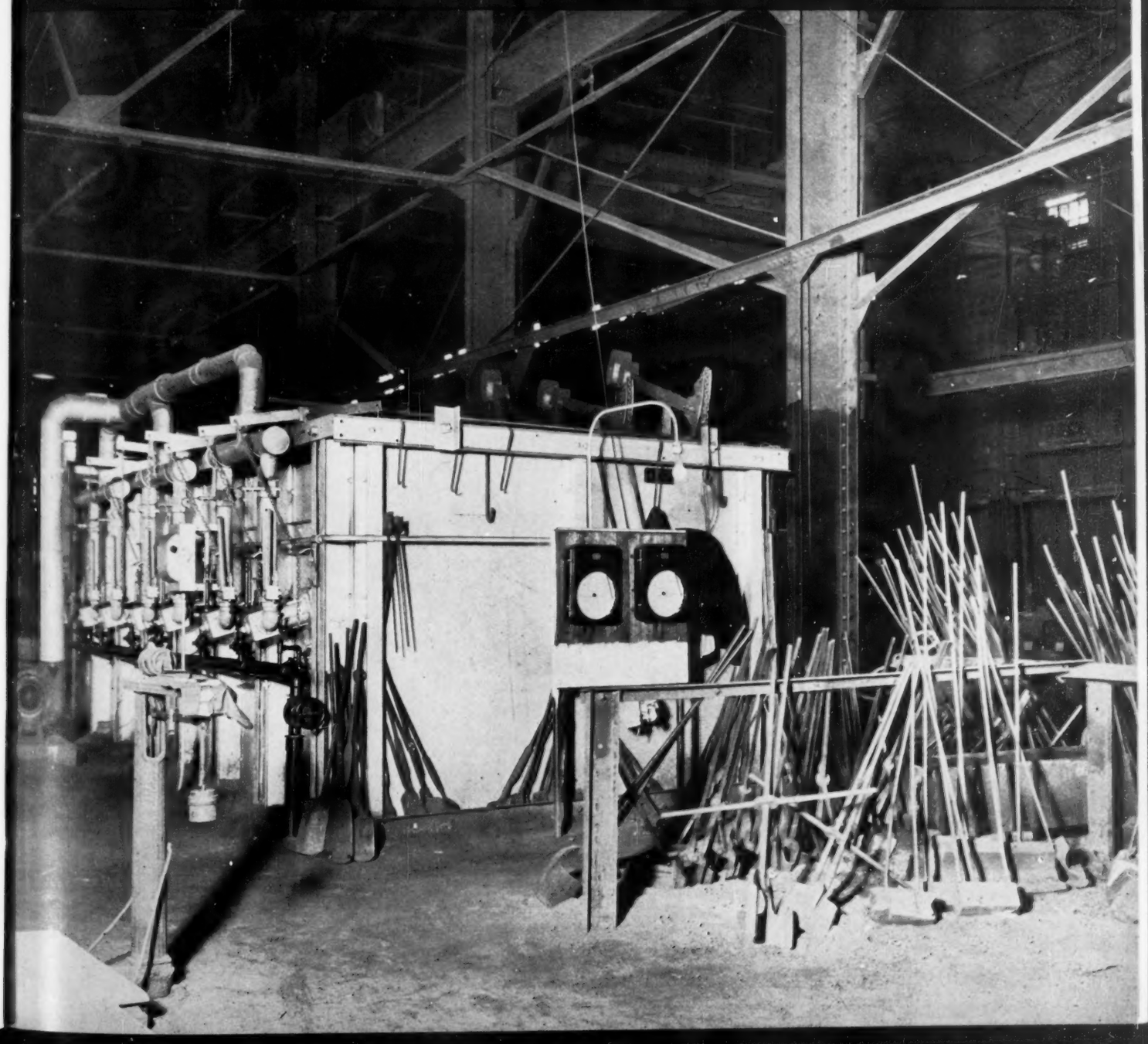
Instruments

THE MAGAZINE OF Measurement and Control

Vol. XIII
OCT.
1940
No. 10



SUPER SPEED takes the BLIND SPOTS out of temperature records

TAG's Super Speed CELECTRAY Recorder has dramatically exposed heretofore uncharted, but vital temperature changes in many industrial processes involving continuous or batch production. Conventional recorders of long cyclic time fail to measure sudden temperature changes caused by chemical reactions. But, the Super Speed CELECTRAY Multiple Recorder takes these blind spots out of temperature records, even though changes may be taking place as rapidly as 200° per minute!

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Translate this super speed, supreme accuracy and operation facility into terms of processing economy and product uniformity, and you'll want to know the whole absorbing story of these competent instruments. They employ the CELECTRAY principle of an inertialess beam of light reflected from a mirror galvanometer, which, in moving on and off a phototube, passes the "controlling edge" of a screen.

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And for all other instrument needs, whether for switchboard or panel mounting, production requirements, or laboratory research...WESTON can supply instruments which likewise combine *unquestioned dependability* and *time-saving facility* to the highest degree. » » » For complete information on the WESTON AC Clamp-Ammeter and other WESTON instruments, 'phone the WESTON representative near you, or write to Weston Electrical Instrument Corp., 591 Frelinghuysen Avenue, Newark, New Jersey.

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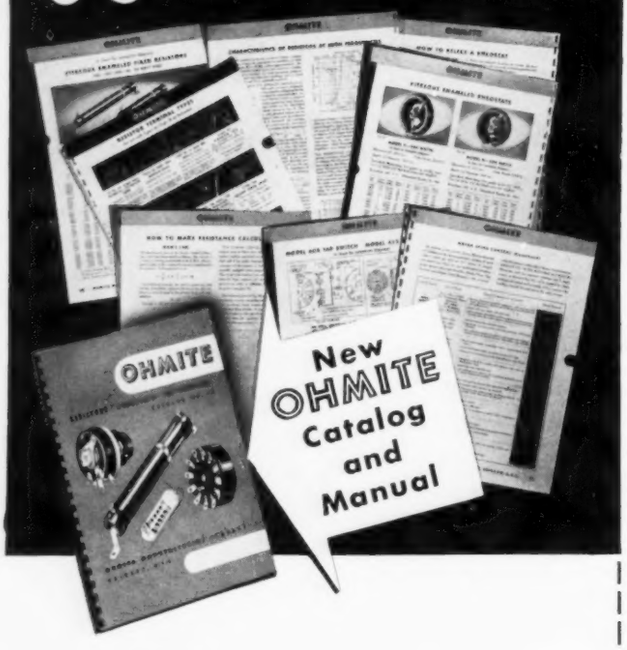

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Instruments
THE MAGAZINE OF MEASUREMENT and CONTROL

Vol. XIII **OCTOBER 1940** No. 10

FRONT COVER: Billet furnace instrumentation, Vulcan Crucible Steel Co., Aliquippa, Pa.
Courtesy The Bristol Co.

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Statement of the Ownership, Management, Circulation, etc., Required by the Acts of Congress of August 24, 1912 and March 3, 1933, of *Instruments* published monthly at Pittsburgh, Pennsylvania, for October 1st, 1940.

State of Pennsylvania, County of Allegheny, (ss).

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Richard Rimbach, who, having been duly sworn according to law, deposes and says that he is the Publisher of *Instruments* and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation) etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, to wit:

1. That the names and addresses of the publisher, editor, managing editor and business manager are:

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3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

Richard Rimbach, Publisher

Sworn to and subscribed before me this 30th day of September 1940.

[SEAL] Edward M. Seibert, Jr.

(My commission expires March 24, 1941.)

Instruments
THE MAGAZINE OF Measurement and Control
M. F. BEHAR, Editor

Ten Million Man-years

And What You Can Do to Help

YOU and we—all of us from the North and South and from the East and West—we the people of the United States, through our Congress, have already passed laws appropriating to our Army and to our Navy the amounts of money to pay for seacraft and aircraft, tanks and other vehicles, cannon, machine guns and small arms, uniforms and other supplies, the production of which represents ten million man-years of work.

Ten million man-years!

Cheerfully—yes, joyously—will Americans make this sacrifice in order to keep war away from our blessed land. But the realization of this purpose of National Defense depends on Speed, Speed and more Speed.

If by a miracle this huge production task could be completed in six months (twenty million men working half a year on defense production jobs) the certainty of peace would be absolute: no combination of dictators and their puppets could hope to impose their wills upon us by force.

If on the other hand, Yankee genius were to perish, so that this job of producing defense materials could not be completed in less than ten years (God forbid!) then the forces of evil would enslave us with ease—and government of the people, by the people and for the people would soon perish from the earth.

Speed, Speed and more Speed– That's the keynote of the production job.

The answer is Automatization. An important phase of automatization is Instrumentation.

On this page last July appeared an announcement entitled "To Speed Up National Defense." It announced that the Instruments Publishing Company would award $500 in prizes for essays entered in the 1940 Instrumentation Contest, the theme of which is "Speeding Up Defense Through Instrumentation." We announced that the contest rules would be printed in the August issue; but we suggested that readers should start without delay.

The contest rules were printed in the August issue.

A brief reminder appeared at the bottom of this page in the September issue.

The closing date, announced in the rules, was October 15.

This editorial is being written on October *sixteenth!* Here is the situation: Fewer than twenty manuscripts came in on time, but communications were received from "would-have-been contestants," explaining that they were too busy. Together with similar regrets expressed in the course of conversations, it would seem that a hundred men with ideas on speeding up Defense production did not start writing their essays soon enough.

National Defense is far more important than the enforcement of the contest rules time limit. It has been decided, therefore, to postpone the closing date from October 15 to **November 23.**

All of you who have not yet completed your entries can do so now—but for Heaven's sake don't drag out your work. Never mind polishing up your English. Just tell your story and enclose the necessary diagrams or photographs.

From several letters and conversations, it appears that paragraphs 4 and 5 of the contest rules were read too hastily. Read them with care. Read them twice or three times. Don't think that you have to be an Edison or a Ford. You do *not* have to be the "inventor" of the device or assembly. (No mechanism or circuit in this day and age can be entirely the invention of one man. Back of every useful instrument or automatic system are hundreds and hundreds of scientists and inventors of the past.) Don't be too modest!

Besides, even if you personally had nothing to do with the design of the instrument or automatic system, it is sufficient for you to describe *how* it saves time and labor—or how it *can* speed up various operations and processes in the production of national defense material.

A bright high-school boy visiting your plant and seeing what you are doing in your daily work might win a prize by reporting what you are doing. You are more than a schoolboy.

The rules appear on page 322.

One last word, quoted from the July announcement:

This is NOT a duplication of governmental plans pertaining to new inventions. Patentable ideas are not desired in particular. What the Jury of Award will probably prefer is a brief description of *what you are doing at this moment* to speed up your own applications with the aid of measuring and controlling instruments, meters, automatic inspection devices, automatic gages, etc. In other words, if you have put into practice any way of using instruments to speed up preparation, production, transportation, etc. —any way which others can easily copy—then this is the best possible kind of an idea to submit, because, if widely adopted, it will reduce the time lag and speed up production.

Chicago Society for Measurement and Control

Open Meeting—Monday, November 4.

HIGH SPEED PHOTOGRAPHY AS AN INDUSTRIAL INSTRUMENT

By: Harry F. Bryan,
Research Engineer, International Harvester Co.

This talk will include the showing of moving pictures taken at the rate of 2,000 frames per second and will show injection pump sprays in pressure bombs, combustion pictures taken through a quartz window in an engine, valve spring bounce, mechanism movements and other interesting phenomena.

Central Y.M.C.A. Auditorium, 19 So. LaSalle St., Chicago, Illinois.—Dinner at 6:30—$1.25. This is an open meeting and all are invited. If you cannot come to the dinner, come for the meeting and discussion at 7:30.

Please 'phone dinner reservations to Carl Hope at Canal 4100, or address the Society at 2626 W. 31st Boulevard.

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THE MONTH'S NEW INSTRUMENTS

In this department we strive to report each month ALL the new devices for measurement, inspection, testing, metering and automatic control—in the form of concise technical descriptions. When writing to manufacturers directly, please mention this department as your source of information. Or write to Information Section, Instruments Publishing Company.

"Straight-and-angle" Thermometers

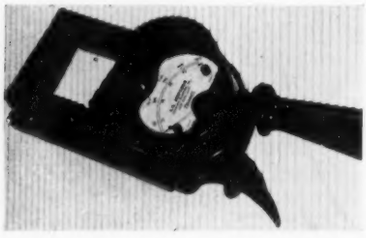
Name of new "Philadelphia Stran Thermometer" is derived from "straight" and "angle" but this name is incomplete for it should include "side." Reason: this new form of the industrial thermometer may be placed as a straight and an angle instrument; also as a right-side or as a left-side thermometer. Five-inch silvered scale, bronze case, yellowback tubing.—*Philadelphia Thermometer Co., 915 Filbert St., Philadelphia, Pa.*

Thermocouple Fitting

To facilitate thermocouple replacement, a Universal Union for angle-type couples is in two halves which fit snugly together in a ground joint making it vapor- and fume-tight. By unscrewing a single clamping nut—which cannot fall off—the thermocouple's hot leg can be detached; or it can be rotated to any angle between 90° and 180°, and locked firmly in place. —*Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia, Pa.*

Dual-range "Clipon" Ammeter

Dual Range "Clipon" Ammeter, 0-100/500 amps., has a guaranteed accuracy of ±2% of full-scale, and its clips are completely encased in Bakelite. Not visible in illustration is a hole provided in the handle for a carrying strap.—*Ferranti Electric, Inc., 30 Rockefeller Plaza, New York City.*

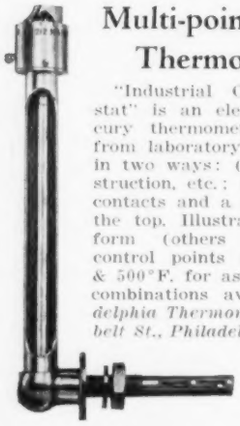


Conductivity Bridge

New "IB" model of "Type RC" Conductivity Bridge (see *Instruments*, June 1939, page 157) is similar in all respects to earlier models except that it is equipped with a vacuum tube oscillator to supply the bridge source to 1000 cycles. Completely self-contained, it operates from 100- to 135-volt 50-60 cycle line. (Companion model for 220-V, 25-c.)—*Industrial Instruments, Inc., 155 Culver Ave., Jersey City, N. J.*

Resistance Box

New "Determohm Resistance Box" is available in two ranges, one of 1 to 9,999 ohms and the other of 10 to 99,990 ohms (in addition to the 100 to 999,900 range previously announced). Accurate to ±5%, it is designed for industrial and laboratory uses, for radio service men, engineers, experimenters, and schools. Wire-wound resistors are connected to tap switches. "Determohm" may be connected directly in radio and electrical circuits which do not cause instrument to dissipate more than one watt for each tap in the circuit. Overall dimensions 6 3/16" × 8⅛" × 3¼".—*Ohmite Mfg. Co., 4835 Flournoy St., Chicago, Ill.*



Multi-point Mercurial Thermoregulator

"Industrial Control Visualstat" is an electric-contact mercury thermometer which differs from laboratory thermoregulators in two ways: (1) protected construction, etc.; (2) a plurality of contacts and a selector switch at the top. Illustrated is side-angle form (others available) with control points at 100, 212, 325 & 500°F. for asphalt tests (other combinations available). — *Philadelphia Thermometer Co., 915 Filbert St., Philadelphia, Pa.*

AC-ME RECORDING GRAVITOMETER

ACCURACY
with
SIMPLICITY
for
RECORDING
SPECIFIC
GRAVITY OF
GASES

— FEATURES —

Requires minimum of maintenance

No rotating parts

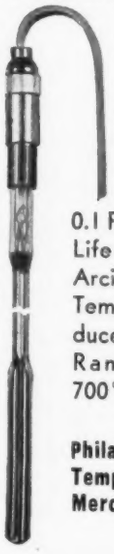
Automatically compensated.

Manufactured by

THE REFINERY SUPPLY CO.

TULSA, OKLA. HOUSTON, TEX.

Philadelphia Merc-to-Merc Thermo-Regulators Feature



Mercury to Mercury Contacts : Increased Contact Capacity : Sensitivity within 0.1 F. Exceptionally Long Life and Stability : No Arcing : No Oxidation : Temperature Lag Reduced : Temperature Ranges adjustable to 700°F.

●

Philadelphia Merc-to-Merc Temperature Controls and Mercury Plunger Relays

●

The Philadelphia Thermometer Co.
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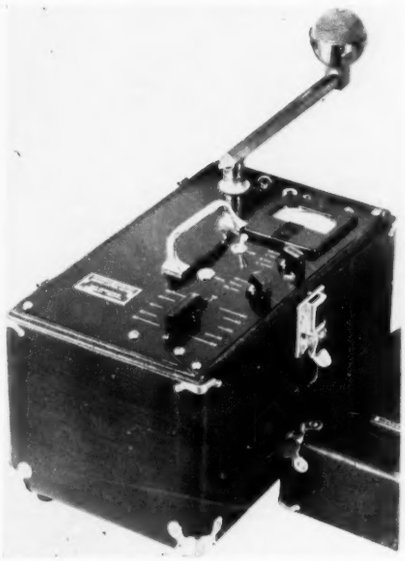
WRITE FOR CATALOGUE
No. 104.
Oldest Thermometer Manufacturer in Philadelphia

Sound Level Meter

New portable sound-level meter weighs 19 lbs., has a range of 24 to 120 db ("from the rustle of leaves to the scream of a factory whistle"), consists essentially of a



microphone, an amplifier and an indicating instrument. An arm extension protects microphone from sound reflected from case. Amplifier consists of five resistance-coupled stages: battery-operated tubes are mounted on a shock-proof base. A switch permits selection of one of three ear-weighting networks, 40 db, 70 db or flat frequency response giving instrument a response similar to that of human ear. In field use it is calibrated by applying a precision mouth-blown calibrating unit to the microphone. After adjustment, a single knob controls the instrument, which is designed to perform in accordance with A.S.A. standards for sound level meters. Complete outfit comes in a carrying case 12¾" long, 7¾" wide and 9¼" high. *Vibration velocity unit* may be substituted for microphone on the instrument, thus providing a means of measuring vibration as well as noise.—*General Electric Co., Schenectady, N. Y.*

Cathode-ray Oscillograph

New "Model RFO-5" oscillograph for complete visual analysis is designed for frequency-modulated, amplitude-modulated and television servicing, "single or consecu-

tive stage-by-stage trouble-shooting from antenna post to speaker." It has self-contained wide-band f-m. oscillator for f-m. and television receivers and narrow-band f-m. oscillator for amplitude-modulated receivers. Also, demodulator, video amplifiers, signal tracer and visual a-c. vacuum-tube voltmeter with a range from 0.2 to 1000 volts. Wide-band f-m. oscillator can be modulated from external sources for user's own laboratory checks.—*The Hickok Electrical Instrument Co., 10329 Dupont Ave., Cleveland, Ohio.*

BAILEY METER CONTROL SYSTEM

The Mark of Effective Control

Process Control for sensitive, stable automatic control of temperature, pressure, liquid level, flow and other factors as applied to industrial processes. Responds to changes quickly, without overtravel or hunting. Ask for Bulletin No. 101.

Combustion Control that is simple but *complete* for providing economical operation of boilers of 200 h. p. and larger. Details in Bulletin No. 102.

Recorder-Controller

Boiler Meters for recording combustion conditions and guiding boiler operators. Described in Bulletin No. 44.

Multi-Pointer Gages for indicating factors such as draft, pressure, temperature and speed. These Gages are available with any number of pointers and any scale combination; in either the oil sealed bell or diaphragm construction.

Control Drive

Flow Meters for indicating, recording and integrating the flow of steam, water, sewage, air, gas and other fluids. Bulletins No. 39 and 300.

Recorders for pressure, temperature, drafts, liquid level and other factors.

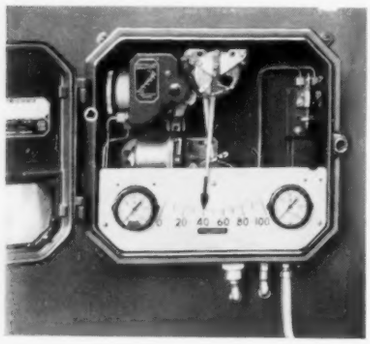
G-3

BAILEY METER COMPANY

1041 Ivanhoe Rd., Cleveland, Ohio

Pneumatic Telemetering System

For indicating, recording or controlling process variables remote from the point of measurement, new "Taylor Remote Pneumatic Transmission System" utilizes mak-



er's standard instruments. It may consist of one or two transmitters connected to a receiver or one or more receiving instruments, not necessarily near each other, and as far as 1000 feet from transmitter. Transmitters or receivers may be indicating, recording or controlling types. Air pressure is transmitting medium, with $\frac{1}{4}$" O.D. copper tubing as connection. Accuracy is within $\pm 1\%$ of scale range when properly installed. Speed depends upon distance—the maximum lag being 1 second per hundred feet of connecting tubing. System eliminates electrical hazards in explosive atmospheres. It measures, transmits and receives continuously. —*Taylor Instruments Companies, Rochester, N. Y.*

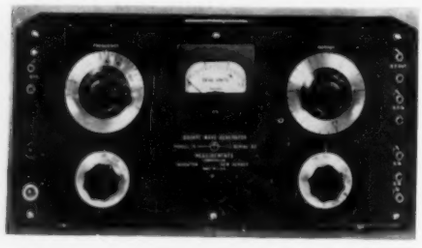
Gage Blocks

"Mechanic's Own" is name of latest addition to line of "Ultra-Chex precision length standards." It consists of five gage

blocks (1", 0.500", 0.250", 0.125" and 0.0625",)—*George Scherr Co., 128 Lafayette St., New York City.*

Square Wave Generator

New "Model 71" is a completely self-contained source of square waves suitable for testing all audio and video amplifiers for both high and low frequency cutoff and



phase shift. No driving oscillator is required. Instrument includes a square wave modulator for producing square r-f. pulses. Resulting square wave carrier can be utilized for many new measurements on receivers and broad-band amplifiers. This square wave modulator is an amplifier whose gain is controlled by the square wave generator. Frequency range: 10 to 100,000 cycles/seconds continuously variable, derived from built-in oscillator. Range can be extended. Output voltage: 150 volts peak to peak, balanced to ground. Attenuator and output meter provide unbalanced voltages to ground of 0 to 75; output impedance 20 ohms per volt. Wave shape is independent of attenuator setting. R-f. modulator: 5 volts maximum carrier input—translation gain of modulator approx. unity. Output impedance of modulator 2500 ohms. Power supply: 115 volts, 60 cycles, self-contained. —*Measurements Corporation, Boonton, N. J.*

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SIMPLEST AND MOST EFFICIENT
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THREE DIFFERENT STYLES
Portable Standard with single electrical zero return.
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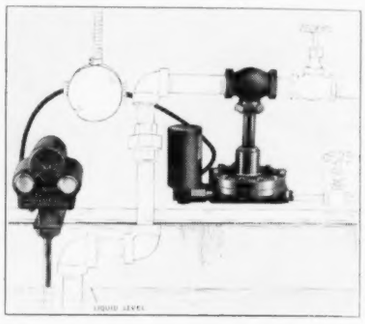
National Electric Controller Co.
5317 Ravenswood Ave., Chicago, Ill.

Temperature Controller

New "Cromicrostat" combines a sensitive (0.5°F.) rod thermostat and, normally, a heavy-duty electrically-commanded hydraulically-operated steam valve. Differential-



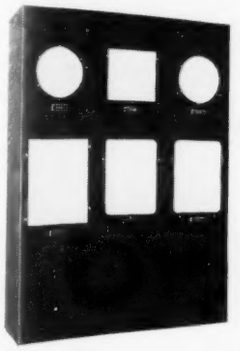
expansion thermostat stem length 24" to 48" (brass outer tube regular, other materials available). Range up to 500° F. with a working span of 50° or 100° (the 50° spread being recommended where the half-degree throttling is desired). Red and green lamps signal action. Valve controls steam to 15 lbs/in.^{2} (higher pressures special), requires water pressure of 20 to 125 lbs./in.^{2}. Remote-control electrical requirements: 110-volt 60-cycle 14 watts (others special). All parts corrosion-resistant. Also available are combinations of thermostat with gas valves, magnetic contactors, etc.—*Controls, Inc., Towaco, N. J.*

Automatic Timers

A new series of 128 models of interval timers and time delay relays has just been announced. Units are powered by slow-speed, self-starting synchronous motors, and

equipped with "fast-acting silver contact micro-switches." Ranges in split-seconds, seconds, minutes or hours. Manual or automatic reset models for built-in flush panel mounting, enclosed surface mounting or wall mounting.—*Paragon Electric Co., 37 W. Van Buren St., Chicago, Ill.*

FALSTROM



STEEL PANELS

FALSTROM Precisioned Steel Panels are specified by engineers for their Strong Construction . . . Adaptability . . . Fine Appearance . . . for use in—

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Send blueprints. Write for bulletin P-10

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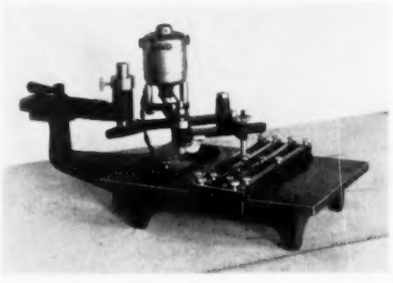
—MICO—
ENGRAVER



A versatile motor-driven pantograph machine of high accuracy for production and experimental work.

Produces excellent engraving on metal or plastic parts with characters 1/16" to 1/3" tall.

Attachments adapt it to small or large work on flat or curved surfaces.

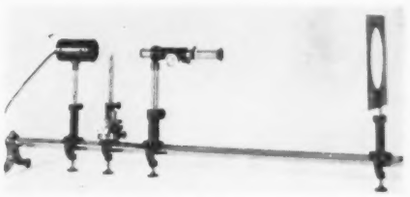
Literature and samples of work on request.

Price: $113.50 with master type.

Mico Instrument Co.
16 ARROW STREET
CAMBRIDGE, MASS.

Projection Comparator

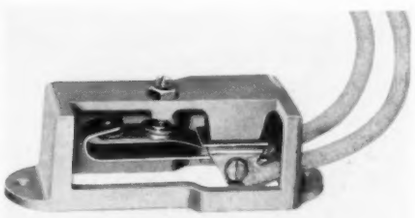
Using standard optical bench parts, projection comparator gives magnification of 50× and more. Parts are interchangeable so that other equipment may be added as



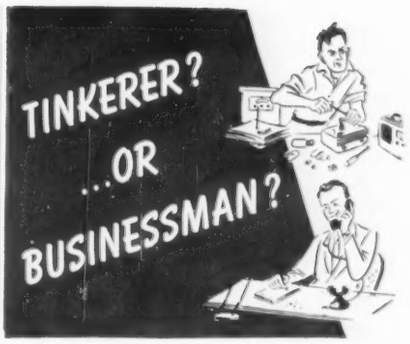
desired. Units such as microscope, lamp and swiveling clamp can be put to other shop uses. Projector consists of a high-powered lamp (operating on a 6-volt transformer) which shines light into horizontally mounted microscope. At extreme right is ground glass screen on which image appears. Each part is mounted on a detachable rod of a standard diameter, which is a good sliding fit in a right-angle clamp. Clamps, in turn, are mounted on a long square rod, provided with detachable end supports. Between light source and microscope is mounted a standard swivel clamp in which is detachably inserted a rod having its upper end threaded, to which can be attached a small platform with centers, V-block or other method of holding the object to be examined. Swivel clamp's upper portion rotates accurately on lower portion, a scale reading the rotation directly to 5°; 1° can readily be estimated. Upper portion of swivel clamp is provided with a cross-slide operated by a screw, having a 1" range of motion. In operation, swivel clamp is moved back and forth in front of microscope until a clear image of the object is focused on screen. Final focusing is by means of rack-and-pinion on microscope. For measurement on screw threads, swivel clamp should be rotated to correspond with helix angle. Image is clearly visible in a well-lighted room. In place of the ground glass screen, user can substitute drawings on translucent paper with which the object can be compared. No refocusing is necessary when it has once been adjusted to a given object.—*Gaertner Scientific Corp., 1211 Wrightwood Ave., Chicago, Ill.*

Strip Type Thermostat

For controlling temperature of flat electrically heated surfaces, new "UL Strip" type thermostat is approved by Underwriters' Laboratories for 1500 watts at 115-



230 volts a.c. Element, with electrolytic silver contacts and accessible adjustment screw, is mounted in a cast aluminum housing which conceals terminals. 12" of asbestos-covered lead wires supplied with each unit. Available in maximum operating temperature ranges of 300, 450 and 700°F., normally closed contacts to open with rise in temperature, or normally open to close with rise. 5°F. temperature differential. Adaptable for controlling air temperatures by perforating the aluminum housing. Overall dimensions: 4½" × 1½" × 1¼" high. Mounting centers: 3¾".—*George Ulanet Co., 89 Kinney St., Newark, N. J.*



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Means MORE Time to Build Business!

RCA RIDER CHANALYST

Yesterday's servicing methods were good enough . . . *for yesterday*. But progressive servicemen *today* demand methods that fix sets quicker. They spend less time bending over receivers—more time going out after business . . . developing business-getting ideas . . . *building* their business.

Signal-tracing with the Rider Chanalyst *takes less time!*

Greatest advance in radio servicing instruments since servicing began, the RCA Rider Chanalyst uses the newest method of attack: *the signal itself*, common to every radio. It's an investment worth investigating! Ask your RCA Distributor for on-the-circuit proof of the Chanalyst's effectiveness by means of the Dynamic Demonstrator.

"Line 'em up" Faster, Easier, Better!
NEW RCA A. C. TEST OSCILLATOR
No. 167 . . . $34.50 to servicemen

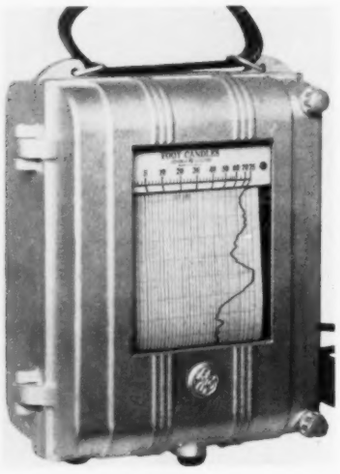
★ New, Accurate, Easy-Reading Dial
★ 100-30,000 KC. Fundamentals: 6 Bands
★ Full 1.0 Volt Maximum Output
★ 30%, 400-Cycle Internal Modulation

Over 380 million RCA Radio Tubes have been purchased by radio users. In tubes, as in parts and test equipment, it pays to go RCA All the Way.

RCA Test Equipment
RCA Manufacturing Co., Inc., Camden, N. J.
A Service of the Radio Corporation of America

D-c. Strip-chart Recorders

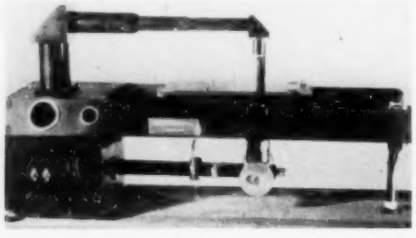
Maker's "Type CF" line of inkless recorders (see *Instruments*, Feb. 1938, page 65) has been extended to include d-c. instruments (Type CF2) available as volt-



meters, ammeters, millivoltmeters, milliammeters, and microammeters in ratings down to 125 microamperes full-scale. New CF2 instruments provide continuous operation for 30 days without attention, may be operated at temperatures from —10°F. to 120°F. Concentric-magnet d-c. measuring element is thoroughly shielded from stray magnetic fields. Accuracy is within 2% of full-scale value.—*General Electric Co., Schenectady, N. Y.*

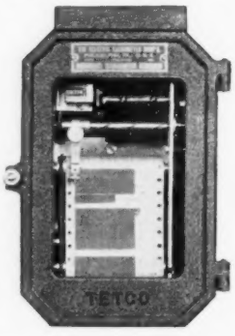
Non-recording Densitometer

Designed for convenience, this new instrument is of projection type, using a "magic-eye" tube as a null balance indicator. Projected image is magnified 10



times to give a field of 2.5". Exit slit is 0.010" wide and 0.750" long. Measuring and projection trains have a common light source. A cam aperture serves as measuring element, covers a range of one density unit with a scale of 100 divisions. Density range is shifted by changing a second aperture in measuring train. Fine adjustment for setting zero at any desired low-density level. Mechanically, unit provides coverage on the plate of an area slightly less than 4" × 10" by means of transverse and cross slides. Transverse carriage is provided with direct and 7:1 vernier handwheels. For precise wavelength measurements over a range of 13 mm., a micrometer reading to 0.0025 mm. is provided. It can be shifted for use at any position of the transverse carriage. For rough measurements, a 20-cm. scale can be read to 0.10 mm. Cross carriage is provided with a quick shift device which in normal position locks carriage and allows fine-adjustment knob to be used. Balancing circuit is said to be extremely stable. Two high-vacuum photocells in a null circuit act as detectors.—*Baird Associates, 20 Palmer St., Cambridge, Mass.*

TETCO
Speed Recorder



Creates a permanent time record on a waxed chart. Accurately records rate of production, time and duration of stops, total quantity produced.

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SMALL DRILLS
from .0016 up to .1969 inch diameter, all sorts of small turned parts.
Small wood screws in brass, steel, etc., turned from the bar.
BLACK GRINDING DISCS

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Enter the $500 Prize Contest

See Pages 285 and 322

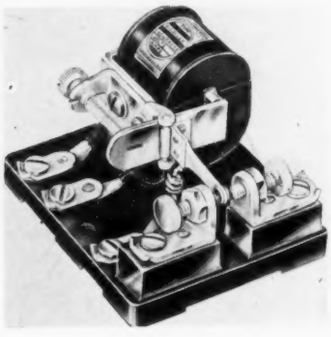
Wide Band Signal Generator

New "Model 188X" wide band universal crystal controlled signal generator is specifically designed for frequency modulation and amplitude modulation servicing. With

frequency coverage on fundamentals from 100 kc. to 133 Mc., the output selections include: electronic controlled wide-band frequency modulation output with 750 kc. sweep for alignment of f-m. and television receivers. F-m. output, modulated internally, at 400 cycles with F.C.C. standard f-m. sweep (150 kc.) Amplitude modulation output as well as narrow band frequency modulation (30 kc. sweep.) A-f. outputs of 400 cycle fixed and 50 to 10,000 cycles variable are available. Crystal-controlled outputs, modulated or unmodulated, accuracy better than 0.01%, are included with frequency coverage from 100 kc. to 10 Mc. Also furnishes synchronized sweep voltage for oscillograph use. Oscillator includes built-in power supply. It is standard for any 110-volt a-c. line, 40 to 65 cycles. All necessary cables, complete manual and instruction book, are furnished—*The Hickok Electrical Instrument Co., 10514 Dupont Ave., Cleveland, Ohio.*

A-c. & D-c. Relays

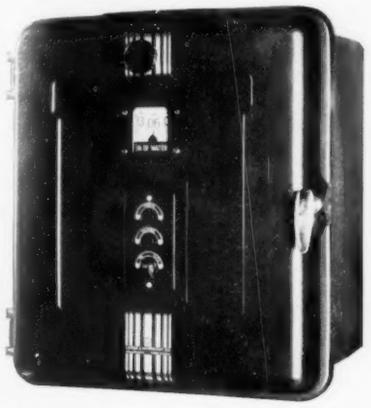
New "Circle" line relays are said to be 50% more efficient on a.c. than any known sensitive relay on the market. They are further described as "exceedingly rugged



and develop unusually high contact pressure and wipe." They can be made in d-p.d-t. Units are assembled on a molded Bakelite base which can be utilized for front or back connections on panel board mounting. Magnetic structure is of a special heat-treated alloy. Novel hinge arrangement using a stainless steel pin with brass bearings is said to assure long life "under the most severe operating conditions."—*Allied Control Co., Inc., 227 Fulton St., New York City.*

Furnace Pressure Controller

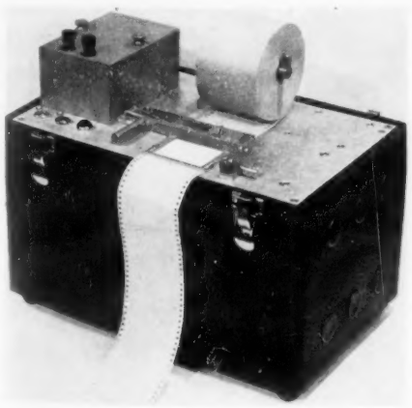
Flexibility of installation, convenience of operation and ease of adjustment are claimed for completely redesigned industrial Furnace Pressure Controller. Die-cast case



matches most "Micromax" instruments. Designed primarily for flush-mounting, it can be panel-mounted at the factory and shipped, completely connected and wired, to user's plant. Built into the controller door are a selector switch and a push-button station, enabling the operator to take over on manual control at a moment's notice. Also located at outside of door is control setting knob. Through a window, just below it, can be seen a stationary pointer and a movable dial. Dial is calibrated from —0.05 to +0.15 inches of water. (Pressures up to ±5″ can be accommodated.) A turn of the control setting knob rotates the dial, and adjusts the pressure value. Adjustments are said to be facilitated by two sets of convenient weights. One adjusts the zero setting of the instrument's mechanical balance; the second adjusts its sensitivity. Both, it is stated, are easy to adjust, and once adjusted, retain their settings reliably. New controller, according to the makers, is strongly built and requires negligible maintenance. It combines with a motor-driven interrupter, a relay, signal lights and a motor drive unit to form a complete L&N system, designed to control the pressures of metallurgical and other industrial furnaces. —*Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia, Pa.*

Power Level Recorder

Purpose back of design of new Power Level Recorder was to offer the most widely useful measuring apparatus for the laboratory: it makes automatically a continu-



ous and permanent record of the transmission characteristics of any electroacoustic apparatus. Announcement emphasizes "a price any laboratory could afford." Instrument can be equipped with input potentiometers of different kinds: db potentiometer in steps of ¼, ½, ¾, and 1 db available; linear potentiometer and also phon potentiometer for loudness measurements. Instrument is built for 110 volts, 60 cycles. Height, 10½″; length, 12″; width, 8″; weight, 22 lbs.—*Sound Apparatus Co., 150 W. 46th St., New York City.*

ASHCRAFT ELECTRIC HYDROMETER

for the
continuous measurement of specific gravity

Utilizes a basically new principle of liquid density measurement by which the specific gravity of liquids may be instantly and continuously determined by immersion during the actual conditions of processing. Also may be used in closed tanks, vats and pipe lines, etc., while fluid is subjected to moderate heat, pressure, flow and agitation. Reads varying density in open tanks by immersion from surface to 50 foot depth. Wired for attachment to standard recorders and automatic density control equipment.

Pamphlet on request.

ASHCRAFT AUTOMATIC CONTROL COMPANY
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IMPROVED "SPOTLIGHTS"

Rubicon MULTIPLE REFLECTION galvanometers have recently been much improved through redesign of optical system. The definition of the line-image is now so sharp that readings can be estimated to .1 of a millimeter division.

These sturdy self-contained galvanometers are available with sensitivities as high as 5×10^{-10} ampere and 1×10^{-6} volt per millimeter division.

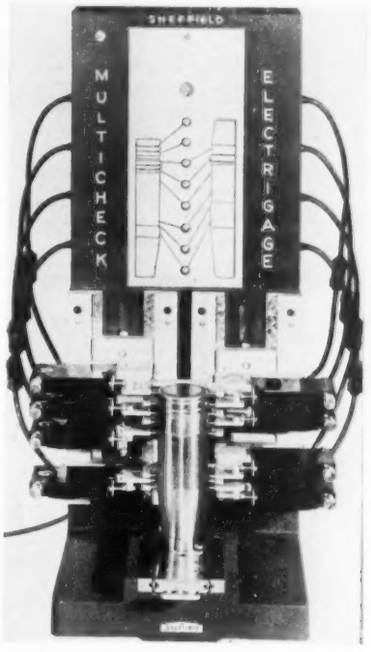
ASK FOR BULLETIN 320

RUBICON COMPANY
Electrical Instrument Makers
29 North 6th St. Philadelphia, Pa.

Galvanometers, Electrometers, Potentiometers, Colorimeters, Wheatstone & Kelvin Bridges, Resistance Standards, Resistance Boxes, Coil Testers Clip-on Ammeters, etc.

Multiple-dimension Automatized Inspector

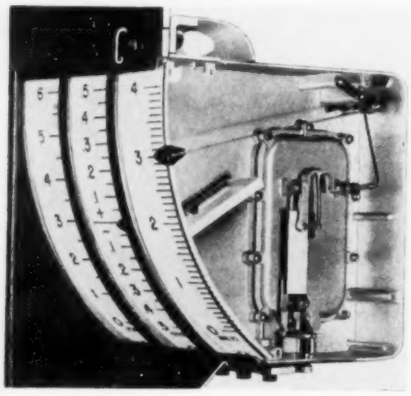
"Sheffield Multicheck Electrigage" is for rapid inspection of mass-production parts having several critical dimensions. Example: the several diameters and shoulder-



lengths of an armature shaft. Applications in National Defense: inspection of timing fuse elements, shell bodies (illustrated), cartridge cases and miscellaneous Army Ordnance work. Measurements of length, diameter and depth are flashed simultaneously by means of colored signal lights as the part being inspected is placed in gaging position. An individual gaging head is incorporated for each dimension to be checked and each head actuates a signal light. When one of these signal lights shows amber, diameter is within tolerance. When light shows red, diameter is undersize; when green, oversize. In addition to individual signal lights (one for each measurement) this gage has a master signal light which shows white when all dimensions are within tolerance. When it shows red, the individual signal port lights are observed. Only one light lens is necessary for each dimension. A plan of the work part is shown, and indicates each dimension with its own signal light. Maker's "Reed Mechanism" (see *Instruments*, June 1935, page 163) is the heart of each "Electrigage" head used in assembly of "Multicheck Gage." This mechanism, it is said, is not subject to frictional wear. Speed in parts per hour depends on size and weight, on number of dimensions, on quality of machining, etc. Example: one operator can check seven dimensions on a 75-mm. shell at the rate of 600 per hour without eye strain. New automatized inspector can be used on parts as large as desired, it is said, or on minute parts such as a pinion less than ⅛″ long overall and less than 3/32″ diam. "Electrigage" head is so designed that it can be applied in various combinations. Each head is a self-contained unit; at any time it can be dismounted and applied elsewhere.—*Sheffield Gage Corp., Dayton, Ohio.*

Multi-point Indicator

For indicating drafts, pressures, differentials, and other factors in boiler and industrial furnace operation, a new multi-point indicator is made up of equal-size gage



units. Zero adjustments and all piping connections for each gage unit are accessible from front of panel. Each unit is designed to be withdrawn, like a book from a shelf, without disturbing other units. Each gage is actuated by a dry-bellows type of diaphragm for ranges from 0 to 50″ of water or by a helical element for pressures above 50″ of water. Gages have 12″ vertical, translucent, rear-illuminated scales. New indicator is supplied with 2 to 16 interchangeable units, is built for either flush or projected mounting.—*Republic Flow Meters Co., 2240 Diversey Parkway, Chicago, Ill.*

Moisture-content Tester

The "Moisture Teller" comprises a motor-driven fan. Air is heated by an electric element and forced through sample being tested. Sample is contained in a sample

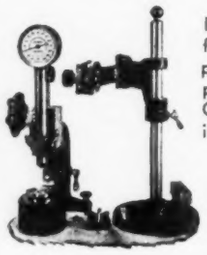
pan with a 500-mesh Monel filter cloth bottom. A timer is used to stop drying process at any predetermined time up to 15 minutes. Granular and fibrous materials require from 1 to 3 minutes to dry; powdered materials and cereals 5 minutes—*Harry W. Dietert, 9330 Roselawn Ave., Detroit, Mich.*

Remote Motor Control

New system of electric remote control adapted to "U. S. Varidrive" motor, makes possible automatic control of take-off shaft speed by means of a thermostat, float switch, etc. It consists of a small worm gear reducer mounted on Varidrive control case and connected to speed-change Varidrive

HARDNESS TESTING...

done WITH NO MENTAL HAZARDS. The SCLEROSCOPE has done it for the past 33 years.



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DEPENDABLE STABILITY
HIGHER OVERLOAD
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Our thermocouples will meet the most rigid requirements. Write your requirements to—

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Open Meeting — Monday Evening, October 28 — 8 sharp — Bureau of Mines Auditorium, 4800 Forbes St.

•

Weather and Weather Instrumentation

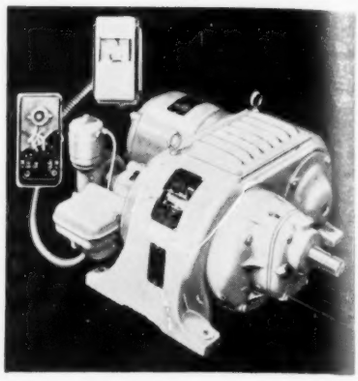
FRED R. MAHER, U. S. Weather Bureau Observer at the Allegheny County Airport, will report on the latest developments in weather instrumentation. His talk will emphasize the air transportation industry, but he will demonstrate the importance of the various measurements to all industries and all occupations.

His talk will be illustrated with lantern slides—a few technical, many non-technical.

Important—Mr. Maher must go on duty at midnight at the airport. Come before 7:45, for the meeting will start on time.

Visitors will be welcome.

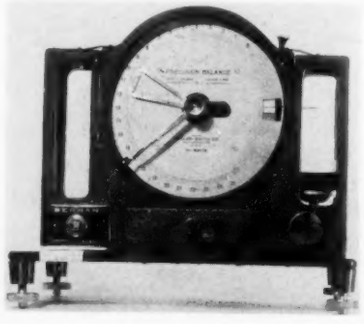
R. J. S. PIGOTT, *Pres.*
FRANK C. MCGOUGH, *Secy.*



control shaft. Pilot motor is operated by thermostat, etc., through a cyclic relay or process timer. Thermostat or float switch controls direction of speed change while cyclic relay governs rate of change of speeds.—*U. S. Electrical Motors, Inc., Los Angeles, Calif.*

Berman Density Balance

Through coöperation of Roller-Smith Co. (mfrs. of torsion balances) there is added to Baird Associates' line a practical form of the Berman density balance for rapid determination of densities of minute sam-



ples of solid materials. (Example: an 8-mg. diamond, measured density, 3.52; calc. from x-ray data, 3.51.) Weight range covered is said to be not available in other instruments.—*Baird Associates, 20 Palmer St., Cambridge, Mass.*

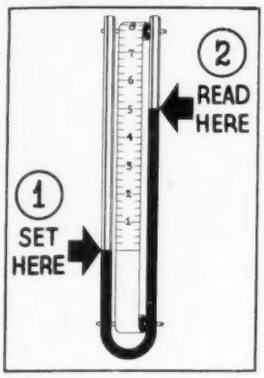
Vibrometer

New "Model 11" vibrometer indicates amplitudes from 0.00001″ to 1″ on the four-decade scale of a 9″ instrument, regardless of frequency or prod pressure. Linearity is

from 15 to 2500 c.p.s.; accuracy 3% on all ranges. Six-tube circuit. Operation from 115-volt 60-cycle supply (other power unit optional). Dimensions, 15″ high × 11″ × 12″. Weight 19 lbs. net.—*Televiso Products, Inc., 2400 N. Sheffield Blvd., Chicago, Ill.*

Direct-reading U-tube Manometer

Diagram shows only the principle of chief feature of new direct-reading U-tube manometers (photograph would not serve purpose). Among other regular and op-



tional features are total enclosure with plate-glass front, cast aluminum or machined steel bodies allowing tube to be recessed, heavy Pyrex tubes quickly replaceable, etc. Manometers are available in sizes from 15″ to 100″ and for line (upstream) pressures up to 700 lbs./in.^{2}. In enclosed models, the "endless-belt" flexible-steel scale is operated from the side.—*Trimount Instrument Co., 332 So. La Salle St., Chicago, Ill.*

Power Analyzer

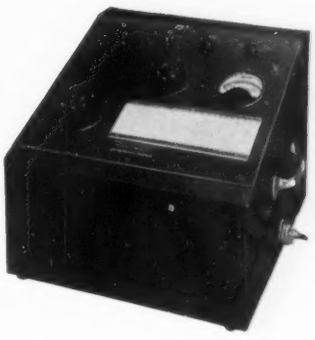
New "Model 903 Universal Power Analyzer" measures polyphase and single-phase volts, amperes and watts. In can be used on single-phase 2-wire, single-phase 3-wire,

2-phase 3-wire, and 3-phase 3-wire circuits. Indicator is maker's "Model 49" square, two-element, polyphase wattmeter. Volts, amperes and watts are all measured by means of suitable switching (while instrument is connected and load is on, if desired). A rotary switch permits current measurement in any of the three wires by inserting ammeter in desired circuit. Voltage can be measured across any two wires of a 3-wire circuit. Ranges in the Model 903 proper: to 650 volts, to 52 amps. and 20,000 watts. Ranges on two multi-range self-contained current transformers are selected by a two-gang rotary switch controlled by one knob on panel. Type C-104 transformers give additional ranges up to 520 amps. and 200 kw. Only one C-104 transformer is required for single-phase two-wire circuits. Two transformers are needed for all three-wire circuits. Space is provided in the carrying case for two of these transformers.—*The Hickok Electrical Instrument Co., 10329 Dupont Ave., Cleveland, Ohio.*

A practical Noise Instrument for *Routine Production Testing* in your plant

Industrial Noise Analyzer RA-273

- Simplified controls
- Rugged mechanical construction
- 38 filter combinations
- Large indicating meter
- Feedback stabilized amplifier
- A. S. A. standard sound meter
- Used with moving coil microphone or vibration unit



FOR THE PLANT—Large number of filter combinations permits segregation of different noises characteristic of specific defects in assembly. Simple controls adaptable to production line conditions. Rugged design insures calibration stability and reliability.

FOR THE ENGINEER—A convenient instrument for wide band frequency analysis, to assist in location and correction of noise sources. Sound level measurement in accordance with A. S. A. standards. For more complete information write to the address below.

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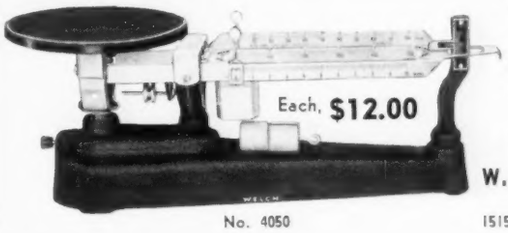
STAINLESS STEEL TRIPLE-BEAM BALANCE
No. 4050



No. 4050

The Beam and all Exposed Parts of Stainless Steel. Stellite Knife Edges. Capacity 1610 G.

Write for Complete Circular

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Do Your Bit for Defense See page 285

Industrial Pyrometry

Second instalment of new and completely revised edition of "Temperature Measurement and Control." The subject of pyrometry will be concluded with Radiation and Optical Pyrometers, etc., in the November instalment which will also include Temperature Control Principles and Modes of Control

By M. F. BEHAR

CHAPTER VIII
"THERMOMETERS" AND "PYROMETERS"

1. Dividing Lines—if any.

It is convenient to treat thermometry and pyrometry as different subjects in a book. In life, these subjects overlap.

Thermometry originally meant the measurement of heat —and still does by inference—but today it means the measurement of temperature. Among instrument men it generally means the measurement of temperatures below dull red, or below 1000°F. which is an easy figure to remember.

Pyrometry originally meant fire-measurement and still means the measurement of "high" temperatures. Again, by agreement, the lower limit of pyrometry is an easily remembered point. But which? Some say 1000°F.; most Europeans say 500°C. which is 932°F. or about 45°F. below the first visible red (where πυρ begins to be justified). Since it's easier to remember the combination of a color and one thousand, let's all stick to the American 1000°F.

A thermometer is an instrument belonging to a class of instruments originally designed and chiefly used for measuring temperatures below 1000°F.

A pyrometer is an instrument belonging to a class of instruments originally designed and chiefly used for measuring temperatures above 1000°F.

A temperature-measuring instrument belonging to a class of instruments originally designed for measuring temperatures below 1000°F. but capable of measuring temperatures above 1000°F. may be called a thermometer or a pyrometer, according to its application. It's all right to call one resistance thermometer a pyrometer when *it* is used above 1000°F.; but it's a mistake to call the whole resistance *class* of instruments "pyrometers."

A temperature-measuring instrument belonging to a class of instruments originally designed for measuring temperatures above 1000°F. but capable of measuring temperatures below 1000°F. (or even below –200°F.) may be called either a pyrometer or a thermometer, according to its application.

The first industrial thermoelectric temperature-measuring instruments were made possible by Le Châtelier's invention of the platinum to platinum-rhodium thermocouple half a century ago. From the start it was found that this couple stood up successfully in service well above *two* thousand degrees Fahrenheit. From the nineties until after the First World War this high-temperature couple was the only standardized couple on the industrial market (even though there were two rival "standards"). All in all, the thermoelectric temperature-measuring devices in common use were pyrometers—and few users even thought of calling them thermometers. Since the twenties, the practical standardization of commercially-available base-metal couples has made possible the manufacture of some industrial thermoelectric temperature-measuring and -controlling devices suitable for practical work below 1000°F. and even down to –300°F. *These* are thermoelectric thermometers.

In a rigorous scientific text-book, the words "thermoelectric pyrometers" would be followed by "or thermometers." The readers will be spared this form of torture.

2. Comparisons of Industrial Pyrometers.

Industrial pyrometers are usually classified as (1) thermoelectric, (2) radiation, (3) optical and (4) fusion. The first three classes, in their industrial forms, are made up with scales across which pointers travel. The fourth class comprises pyrometric cones.

Industrial pyrometers may be classified also into (1) thermoelectric, (2) "hand" and "visual" radiation *and* optical, (3) autometric or autographic radiation *and* optical, (4) fusion.

In the following discussions, therefore, the first three classes (and the types within these classes) can conveniently be compared with one another, but for obvious reasons the fusion cones must be considered as a separate class, not subject to similar comparisons.

A comparison of the three pyrometers along purely scientific lines is not necessary here; but from a practical point of view, comparisons are both obvious and simple:

1. The sensitive element of a thermoelectric pyrometer is immersed in, or in contact with, the body whose temperature is to be measured, whereas radiation and optical pyrometers are sighted from a distance.

2. Therefore, there is an essential element subject to deterioration in thermoelectric pyrometers which is not found in the other classes.

3. With thermoelectric and with automatic or autographic radiation or optical pyrometers one can have temperature indications and records on panel-board instruments and one can readily install multiple-switching arrangements. With a "hand" or "visual" pyrometer one can only measure the temperature of one thing at a time—the object sighted.

4. The conditions for high accuracy in the use of thermoelectric and optical pyrometers are fairly easy to realize; on the other hand, such commonly overlooked factors as invisible gases and vapors may seriously affect the readings of radiation pyrometers. Therefore, the latter are considered "less accurate"—for *use*, not intrinsically—than the other two classes. Under standardized industrial process conditions, however, their indications are just as dependable.

5. Regarding simplicity versus complexity, distinctions have now ceased to exist among all these classes. Certain types and models in any one class are much simpler, and others much more complicated, than types and models in other classes. The same applies to ruggedness: in each class there are both robust and delicate instruments.

6. For measuring the temperatures of objects of small mass (say a few cubic inches of a gaseous mixture, or a solid specimen the size of a dime) the ordinary industrial thermoelectric and radiation pyrometers can seldom be used; whereas most visual optical pyrometers can readily be used—if the body is incandescent. However, "extraordinary" needle-form thermocouples originally brought out for biological and or other scientific purposes are commercially available, so that thermoelectric pyrometers can be used (with care) for micro work.

7. For measuring temperatures of moving objects with the utmost *speed* of which science is capable, there is as yet no industrial (or laboratory) instrument on the market. Meanwhile, industrial thermoelectric, radiation and optical pyrometers can all be "stepped up" but only within certain limitations: paper-thin surface thermocouples wear out quickly; total-radiation receivers ordinarily take at least five seconds to come to equilibrium; photoelectric devices require the use of amplifiers. However, since camera shutters, phototubes and ballistic galvanometers are all commercial articles, one form of high-speed autometric (but not yet autographic) optical pyrometer will no doubt soon appear on the market for measuring the temperatures of moving incandescent objects large enough to fill, say, a 5° cone of view; and a tenth of a second should be ample for each "exposure."

8. There is no commercial pyrometer for measuring the temperatures of *rapidly-moving small* objects. This *double* problem will no doubt be solved soon by the combination of infrared-sensitive photographic emulsions (already available), synchronized shutters (already available), infrared-

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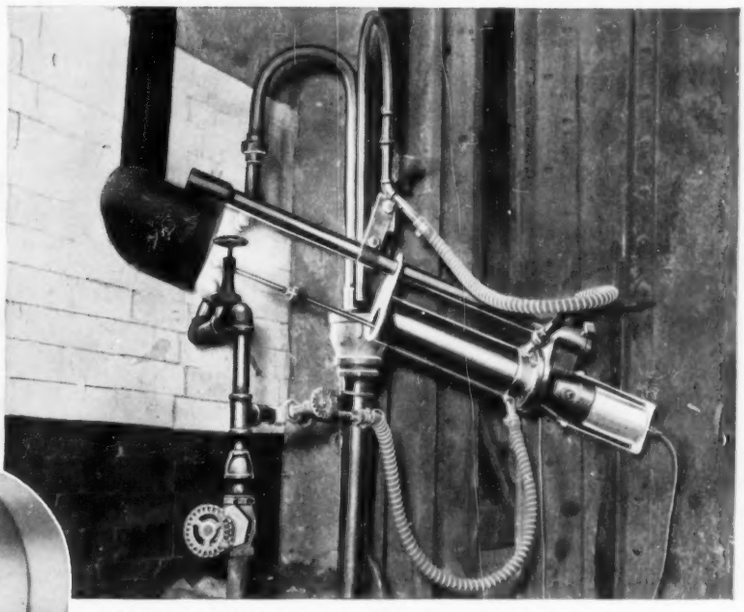

Radiamatic sighted on roof through hole in furnace back wall. Potentiometer continuously indicates and records roof temperature.

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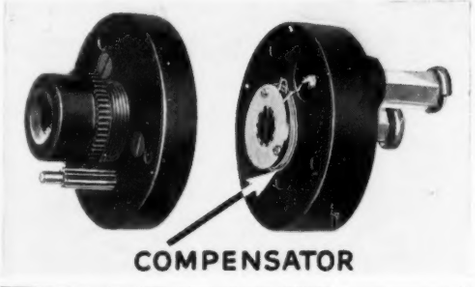
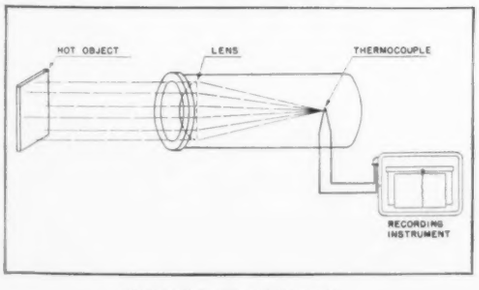


COMPENSATOR



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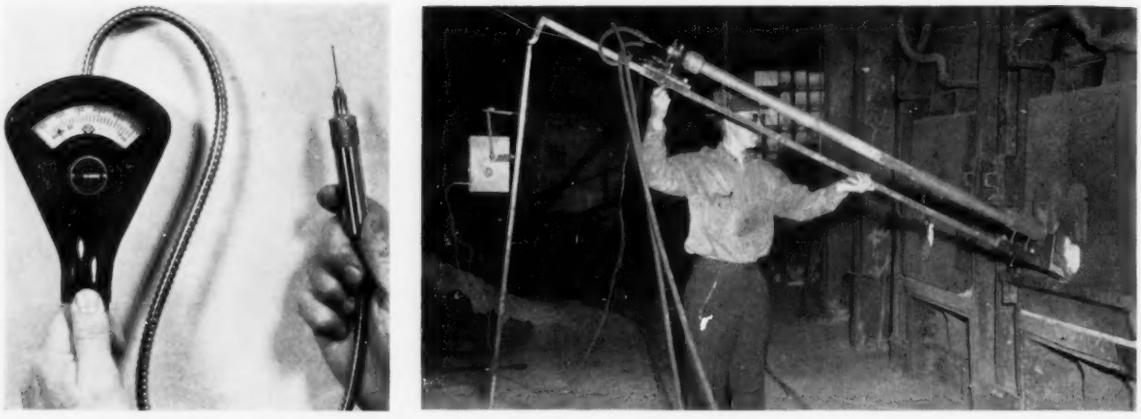

CONTRASTS IN INDUSTRIAL THERMOELECTRIC PYROMETRY

No special effort was made to show "extremes"—these two illustrations simply happening to be readily available. At the left, a needle form thermocouple directly connected to a millivoltmeter for measuring temperatures of plastic materials. (*Cambridge Instrument Co.*) At the right, a thermocouple for measuring temperatures of liquid steel, connected to a potentiometer. (*Filterer Pyrometer Co.*). This thermocouple consists of a silicon carbide rod in a 1¾" diameter graphite tube, both joined at the tip.

transparent lenses (already available), quick-development tanks (already available), densitometric instruments or charts (already available) and brains (already available). Another solution will involve the use of a photoelectric receiver, an amplifier and an oscillograph.

9. As regards the amount of skill required, we must first ask the question, what sort of skill? Certain it is that visual optical pyrometers require some "skill of observation" which the other classes do not. Then too, "skill of sighting" is generally necessary with portable radiation pyrometers, sometimes necessary with optical pyrometers and quite unnecessary with thermoelectric pyrometers. It is possible, however, to sight radiation pyrometers and autometric optical pyrometers once for all by attaching them securely in one position at a definite distance from a peephole or a refractory tube. A certain amount of skill is required regardless of class in following directions when a permanent installation is made. The "maintenance skill" required does not depend so much upon the class as upon the particular construction and circuit of the instrument and of its auxiliaries if any. Experience and judgment are almost always required to detect and promptly remove causes of inaccuracy.

10. Causes of inaccuracy may arise within the elements of the instruments or systems. Some of these will be dealt with below. But the most important causes of faulty indications arise outside of the instrument—in the installation. Some of these have been referred to in a general way in Chapter III. Others will be discussed in Chapters IX to XI. It is well to emphasize the fact that eternal vigilance is the price of continuously accurate measurements of high temperatures in industrial applications. Pyrometers of all classes have been improved, refined, simplified, automatized and made easier to use, but the fool-proof pyrometer has not been invented and perhaps never will be. Nor will anything ever take the place of sound training as a requirement for getting the most out of any class or type of pyrometer.

11. Some of the instruments classified here as "pyrometers" may be used for low temperatures as in refrigeration work, but they seldom are so used in industrial plants (though inexpensive thermocouples are excellent for measuring process temperatures in the production of liquid oxygen, etc.). They may also be used for "water ranges" of temperature, but such applications are also unusual. Only a few special problems in the measurement of temperatures below 1000°F. call for the use of "pyrometers" *in preference* to "thermometers." Among these applications are measuring the temperature of a small sunken surface, such as that of a mold or die, etc. Innumerable other applications are possible by the use of portable self-contained thermoelectric pyrometers and *if* such portable immersion pyrometers were commonly made for thermometric ranges, and were sold at thermometer prices, the practical distinction between pyrometers and thermometers would vanish.

CHAPTER IX

THERMOELECTRIC PYROMETRY

1. Principles.

When two different substances are placed in contact, so many things happen at the interface that even modern science finds it difficult to classify and name all the observable and measurable effects between bodies. In fact, the difficulty is chiefly due to the disappearance of the old familiar distinctions between chemistry and physics. The name "thermoelectricity" suggests that some of the effects between bodies have to do with heat and with electricity much more than with chemistry. That is true: an abridged treatment of thermoelectricity need not mention chemical

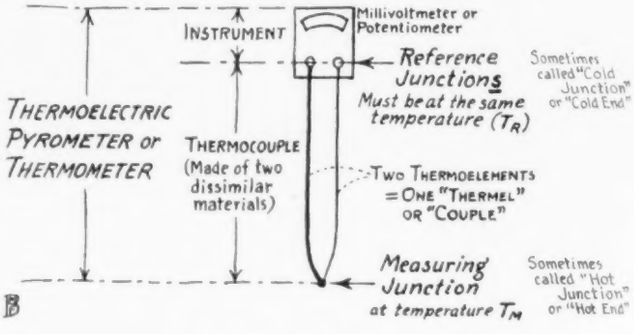
INSTRUMENT
Millivoltmeter or Potentiometer
Reference Junctions
Must be at the same temperature (T_R)
Sometimes called "Cold Junction" or "Cold End"
THERMOELECTRIC PYROMETER or THERMOMETER
THERMOCOUPLE (Made of two dissimilar materials)
TWO THERMOELEMENTS = ONE "THERMEL" OR "COUPLE"
Measuring Junction at temperature T_M
Sometimes called "Hot Junction" or "Hot End"
B

Fig. 1.

effects. Unfortunately, thermoelectric pyrometers actually used in industrial plants are not used in a vacuum but are constantly being attacked by gases and vapors; and some parts are occasionally attacked by condensing liquids. There are no perfect metals or alloys. There is no such thing as complete protection or permanent protection. Moreover, the simplicity of electrical diagrams cannot be realized in actual installations.

For example the usual first diagram of the usual explanation is like Fig. 16. Actually, the simplest possible real, practical, usable thermoelectric pyrometer (a portable one of the "lance" form) requires a diagram like that in the center of Fig. 1.

In connection with Fig. 1 it may not be amiss to state that a thermocouple is a pair of electrical conductors of dissimilar materials, designed and constructed for temperature measurement and control purposes. Therefore, the entire assembly, including protection tubes, etc., is generally called a thermocouple. A thermoelement, however, is one of the pair of conductors, and the word thermoelements refers to the thermocouple proper. In discussions of char-

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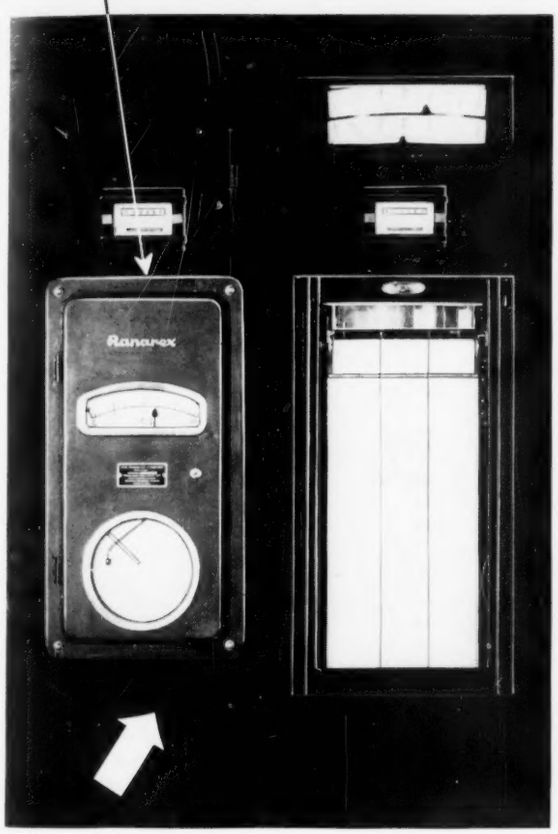

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acteristics, and in circuit diagrams, the word thermocouple (or "couple" for short) refers of course to the thermoelements themselves.

The temperature effect utilized in thermoelectric pyrometry is an effect between bodies. It is an effect between dissimilar materials. It is not a static-electricity effect but a current-electricity effect. The circuit is closed. A current flows in this closed circuit because heat energy has been converted into electrical energy. A thermoelectric pyrometer works because it utilizes an electromotive force, specifically the *thermal emf.* The instrument measures a voltage (usually a millivoltage) produced in its associated circuit. A thermoelectric pyrometer may be called a combination of a millivoltmeter and of a device producing a millivoltage varying with temperature. What depends exclusively on temperature is this millivoltage. The ampere value of the current depends on the circuit resistance (Ohm's law). By using massive—and costly!—rods instead of wires, experimenters have obtained thirty amperes of current, but the emf's were exactly those that would have been obtained with hair-like wires. That our thermoelectric instruments are actuated by voltage, not by current, saves money because it permits the use of thin wires. It saves money also because one instrument can be used for many thermocouples of the same class and resistance.

For each class of industrial thermoelements the relation of temperature difference to thermal emf. is accurately known. The National Bureau of Standards has published tables of values. Good results in practice depend on measuring *this thermal emf.*, and doing our best to avoid measuring anything else. It sounds simple. It would be simple if we could have a circuit consisting only of one pair of perfect thermoelements; just two perfectly homogeneous wires, with no discontinuity of any kind except at the two junctions. Since this is not the case in practice, good results depend on being able to distinguish the thermal emf. from everything else.

(Note. The users of lance form pyrometers, and of other portable permanent assemblies with sealed connections, need not study the following as closely as the users of separable-connection and multi-point systems.)

The thermal emf. (also called Seebeck emf. after its discoverer) is always the resultant of *Peltier emf's* AT junctions, and of *Thomson (or Kelvin) emf's* BETWEEN junctions. A Peltier emf. is an emf. seated in one junction, and varying with the temperature of this junction. A Thomson emf. is distributed along a conductor and is always associated with a temperature gradient between the two junctions terminating this single conductor, so that it varies chiefly with the difference between the temperatures of these two junctions, but it varies also with the temperatures of the junctions and with the temperature distribution along the conductor.

The value of a Peltier emf. is proportional to the absolute temperature of the junction where it is seated. Therefore, the form of a Peltier coefficient is $P = TdE/dT$,—an invariable number for each pair of thermoelements. The manner in which the Thomson coefficient varies (the "law" of this effect) has not yet been determined. Suffice it to mention that the value of a Thomson emf. can only be determined inferentially: by experiments involving Peltier emf's, and by mathematical computations which need not be gone into here. The only mathematics involved in the following development of the subject is "algebraic sum."

"Seebeck equals Peltier plus Thomson" is the familiar memory-aid.

The "plus" means, of course, the *algebraic sum.*

A thermoelectric pyrometer is, in one sense, a reversible heat engine—though a mighty poor one. Thermal energy flows from hotter portions of the system to colder portions, and some of it is transformed into electrical energy which an instrument (itself essentially a "motor") then transforms into the mechanical energy that actuates a pointer. A furnace thermocouple draws heat energy from the furnace atmosphere and therefore cools the furnace atmosphere. When a thermocouple is used to measure the temperature in a refrigerator compartment, there is a flow of heat from the outside to the compartment. In each case, the flow of heat associated with the thermoelectric effect is apart from, and in addition to, ordinary heat conduction.

At this point it may be well to mention that two of the devices sought by inventors are: (1) an efficient thermoelectric engine converting into electrical energy an economically useful portion of heat energy; (2) a thermoelectric pyrometer which does not involve a flow of energy. The potentiometric method is only a partial solution of the second problem.

With these preliminaries in mind, let us try to unscramble the various things that happen.

Before we take up two dissimilar materials, let us consider one. In Fig. 2 are shown three forms of a solid homogeneous material: a bar, a simple closed circuit and a circuit embodying a "motor" or an "instrument." These correspond to the three steps of a reasoning which need not take many words. We heat the material at the left-hand ends. Now, if a pot of water laid on the right-hand side of the bar starts to boil, this will only prove that the material

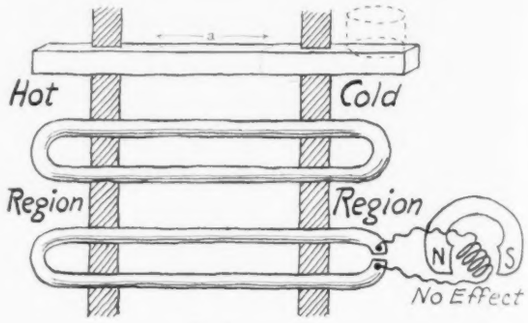

Fig. 2.

is a good conductor of heat. Let us assume that the material is also an excellent conductor of electricity, say pure silver. Electrically, "nothing happens" outwardly at the right-hand end of the bar. Nor does an electric current flow in the simple closed circuit of the second step. And consequently, in the third step, our motor will stand still, or our instrument — however supersensitive its type — will read zero. Furthermore, the instrument will read zero if we alternately heat and cool the left-hand end. Not even a high rate of change of temperature ("thermal shock") at the left-hand end will make the galvanometer needle stir.

Fig. 3.

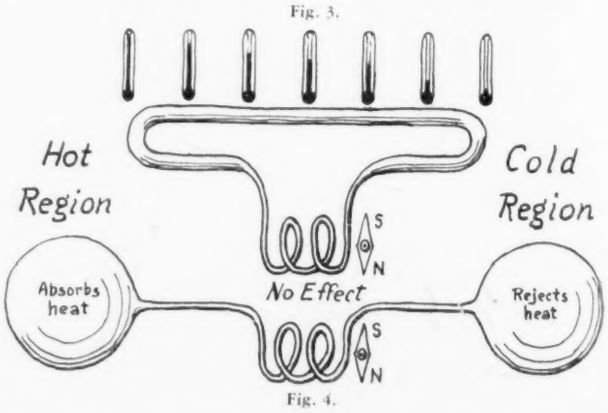

Fig. 4.

Finally, this will be true regardless of any gradient (or gradients) of heat potentials and of consequent electrical potentials in the intermediate portions of the homogeneous bar—or of the other homogeneous conductors. This can be demonstrated in various ways. For example we can take the homogeneous closed circuit of Fig. 2 and, without impairing its homogeneous character, shape part of it into the coil of an instrument as in Fig. 3. There is no effect! To meet the objection that the effects in the two halves of the circuit cancel, we next try a means of transferring a large quantity of heat—the device shown in Fig. 4: if the dumbbell is homogeneous throughout, nothing electrical will hap-

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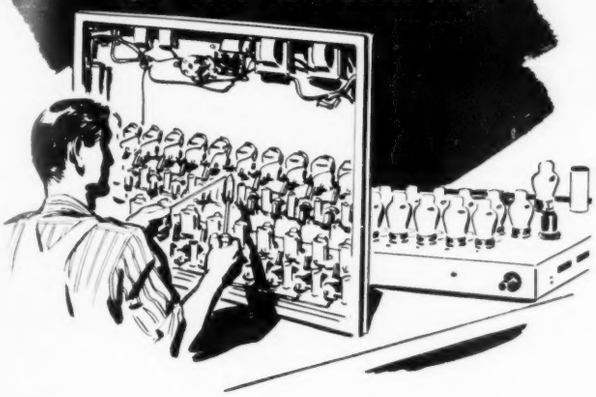

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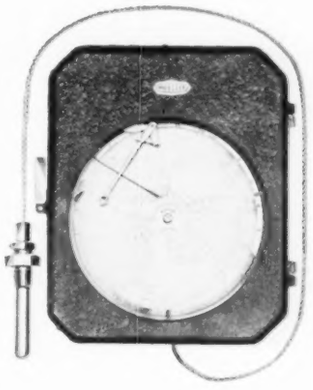

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pen outwardly. For another demonstration, we imagine that the portion "a" of the Fig. 2 bar consists of odd-shaped continuous sections as in Fig. 5. Whatever the individual effects on the individual paths of thermal or electrical energy, the

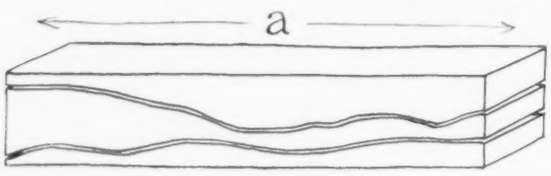
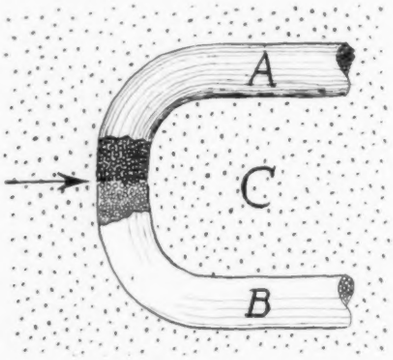


Fig. 5.

sum is the effect of a plain bar. Whatever the number of places where a difference of electrical potential exists by reason of a local temperature gradient, wherever these are, however great the inner local effects, we can still say that no current will flow around the closed circuit, so that nothing of an electrical nature will happen outwardly. Conclusion: it is impossible to use a homogeneous electrical conductor as a heat engine which takes in thermal energy and gives out a thermal emf. actuating a motor or instrument.

Fig. 6.



The practical "moral" is that we can test a thermocouple wire for homogeneity by connecting its ends to a zero-center galvanometer and subjecting various portions of the wire (except the ends near the instrument) to temperature gradients. Any deflection of the galvanometer, in either direction, will be a sure sign of *inhomogeneities*. (A difficult word, but one to keep in mind.)

> It will be a *sure* sign only *if* certain conditions are met —as will be brought out later.

But what has become of the Thomson emf.? Nothing has become of it, for it has not come into being in Figs. 2, 3 and 4. No junctions and no inhomogeneities, no Thomson emf.! So let us see what happens at junctions.

First, one junction.

The simplest ideal case is that of two perfectly inert solids with no activity of any kind at their interface. (Activity here means the conversion of forms of energy.) This case does not exist, but a close approximation is a surface between two dissimilar non-metallic minerals in a geological formation millions of years old. Practical thermocouples, however, must be made of materials which conduct electricity. Such materials are the ones most capable of activity. As a rule, the most active are the metals and alloys. As a rule, too, the pairs of thermoelements which would seem to be among the best from a consideration of their thermoelectric characteristics are among the worst to use. Fig. 6 shows a junction of metals *A* and *B* in a non-conducting medium *C*. Even if this medium were pure air, at room temperature and moisture-free, it would preclude the use of some metals and alloys that rate high in tables of thermoelectric powers.

(Now for a bit of theory: *A* and *B* being metals, some of their electrons are free and exist as an electron gas. When *A* and *B* come in contact, their electron gases start diffusing but the electron gas densities being different there is a net gain of electrons in one metal and a net loss in the other.) That is the theory; the fact is that *A* and *B* being different metals, a difference of potential is set up the moment they touch.

This *contact potential* varies little with temperature and enormously with the surrounding atmosphere. The cleaning and degassing of metallic surfaces and the determination of "true" contact potentials are so difficult that after decades of work, scientists are not ready to publish official tables. (Degassing refers to ordinary gases, of course.) Conclusion: practical thermoelectric pyrometry must depend on gas-free permanent junctions (generally welds).*

The single-junction effect we want to get at, then, is an emf. seated in a permanent junction and varying with the temperature. But let us not name it yet: remember that we are still considering one junction, so that no current flows. The effect, therefore, is a difference of potential. (Analogy, the "open-circuit voltage" of a battery.) The higher the absolute temperature of the junction, the greater this unnamed difference of potential. Outwardly, however, nothing happens. The circuit is open.

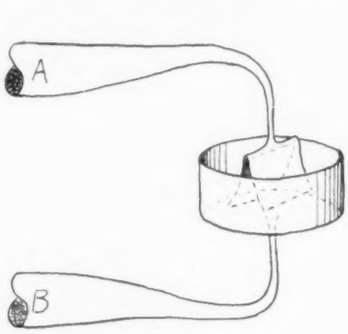


Fig. 7.

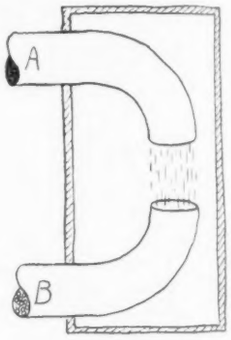


Fig. 8.

With the open circuit of Fig. 6, would it be possible to measure the temperature of the junction by measuring this unnamed difference of potential? Theoretically, various methods are possible. For example we might extend wires *A* and *B* and shape their ends into an "electroscope" as roughly sketched in Fig. 7, being careful to keep metals *A* and *B* perfectly homogeneous. For pyro*metric* purposes we would of course have to have a calibrated electrometer or electrostatic voltmeter. A trifling difficulty (the esu.-emu. ratio) stands between theory and practice: the instrument sensitivity would have to be better than that of today's industrially-usable instruments. But no doubt the proverbial fortune awaits the proverbial inventor.

Instead of trying to measure a small potential difference, could we measure the electromotive force at the single junction (this emf. varies with the temperature) without introducing any other junction to complicate matters? Again, yes, theoretically: in Fig. 8 is sketched a portion of another imaginary instrument—an electron counter. At first thought, the number of electrons passing per second through the otherwise empty space would seem to be an exact measure of the Fig. 6 junction temperature. But the mechanical gap is electrically or electronically closed—and only partly closed. The consequence is that we have introduced many complications in striving for simplicity. Since our electron counter is measuring an actual current, let us replace it by a common microammeter. This done, we have the plural-junction circuit shown in Fig. 1, which is an inventor's dream *realized*.

In the foregoing discussion of the single junction, it was not specifically stated that the right-hand ends of metals *A* and *B* are in a region colder than medium *C* of Fig. 6; and there was only a passing reference to the complications thereby introduced. To save space we may omit another "thermodynamic impossibility" proof, similar to that given in connection with the homogeneous-conductor circuit. It can be similarly proved, however, that it is impossible to use a single junction of two dissimilar materials as a "heat engine" which takes in thermal energy and gives out a thermal emf. actuating a motor or instrument. Whatever

*Some thermocouples for molten metals need not be joined before immersion. See Section 11.

emf. at a single junction could be measured by instruments such as those of Figs. 7 and 8 (and other possible ones), it is not the Peltier emf. The Peltier emf. arises from the fact that thermal energy enters a junction from the outside, causing electric energy to cross the junction in one direction; or heat passes from the junction to the outside, causing electricity to cross the junction the other way; *and* that the "mirror image" of this process goes on at a *second* junction symmetrically associated with this first junction. (What Peltier discovered, however, was that sending a current through a junction heats it or cools it, depending on the metals used.)

In practice, then, thermoelectric effects are ordinary closed-circuit effects between at least two bodies. Again a practical "moral': An instrument "reading" obtained with a thermocouple open is a sure sign of stray currents, wires touching, voltaic currents due to chemical action, or other troubles, generally called "spurious" or "adventitious" emf's in scientific circles, sometimes called "ghost currents" among plant men.

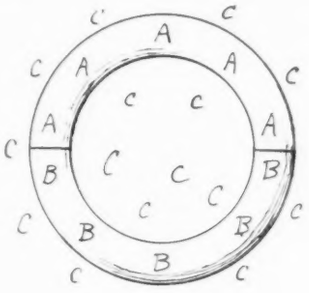
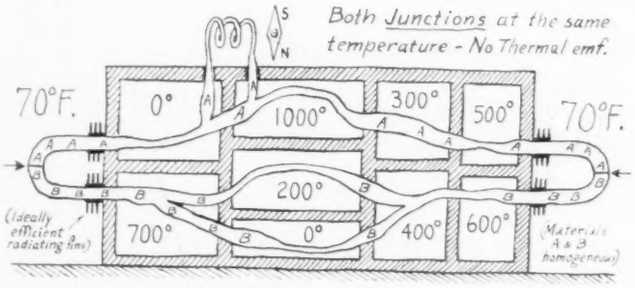


Fig. 9.

Fig. 10.



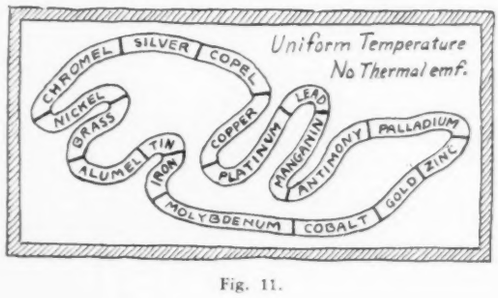


Fig. 11.

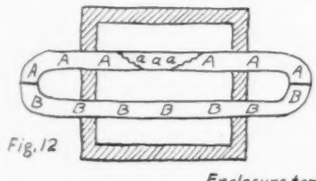


Fig. 12

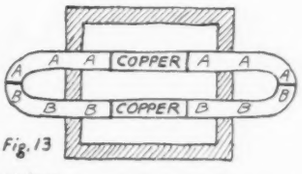


Fig. 13

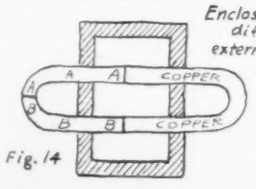


Fig. 14

Enclosure temperature different from external temperature

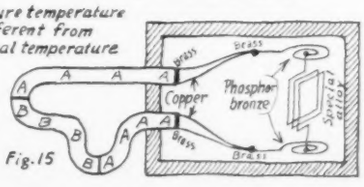


Fig. 15

2. Application of Principles to Actual Circuit

In Figs. 9, 10 and 11 are illustrated the three simple cases of thermoelectric circuits in which there is no flow of electrical energy.

In Fig. 9 the single junction (of Fig. 6) in a uniform-temperature medium C is duplicated at the other end of the conductors A and B. No reference to the reasoning in Section 1 is needed here, for it is obvious without proof that whatever electrical forces exist within the system AB (by reason of whatever differences of properties) these forces cannot be electro*motive* forces. This will be true whatever the shapes of conductors A and B. This will be true even if heat energy is supplied from medium C to the system AB, or vice versa, because although the temperature of medium C will be changing, and with it that of the "doughnut," the two junctions will be at the same temperature at any time.

Figs. 10 and 11 require reference to Section 1 as well as to the preceding paragraph, but the proofs of each case may be left to the reader. It need hardly be stated that materials A and B in Fig. 10 are homogeneous. Any contamination or other cause of inhomogeneity will always introduce *two* additional junctions. Thus, if we represent the homogeneous material by A and the contaminated section by a, the effect will always be

$$AAAAA\,|\,aaa\,|\,AAAAA$$

Reference is made to a contaminated *section* because it is the chief offender in practice. A tiny inhomogeneous spot caused by one drop of perspiration would seldom create an emf. because its ends would be at the same temperature. But exposure to various atmospheres causes long sections to be contaminated and such a section, being unsuspected, is allowed to be exposed to temperature gradients, whence —always—emf's causing errors. An inhomogeneous section is shown in Fig. 12 which is the first of a quartet of problems. The same question "will there be a thermal emf.?" applies to all four diagrams. The answers may not all be "no" but they—and the proofs—may again be left to the reader. (Hint: don't be deceived by the appearance of symmetry. Second hint: turn the page so that the right-hand side will become the top.)

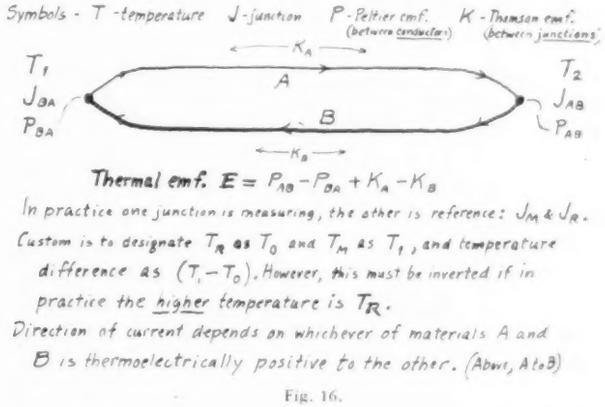
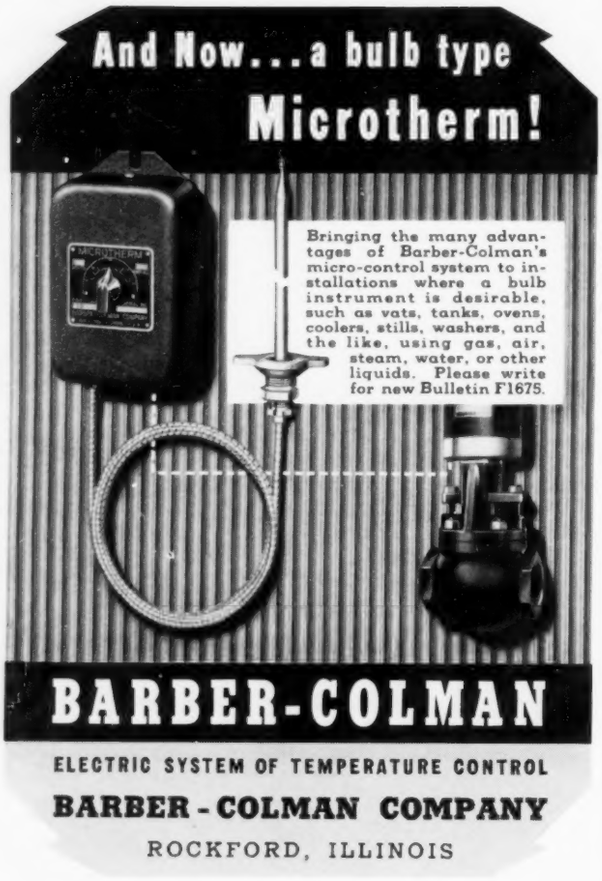

Symbols - T -temperature J -junction P -Peltier emf. (between conductors) K -Thomson emf. (between junctions)
K_A
T_1
J_{BA}
P_{BA}
A
B
T_2
J_{AB}
P_{AB}
K_B
Thermal emf. $E = P_{AB} - P_{BA} + K_A - K_B$
In practice one junction is measuring, the other is reference: J_M & J_R.
Custom is to designate T_R as T_0 and T_M as T_1, and temperature difference as $(T_1 - T_0)$. However, this must be inverted if in practice the higher temperature is T_R.
Direction of current depends on whichever of materials A and B is thermoelectrically positive to the other. (A to B, A to B)

Fig. 16.

From now on the diagrams may be conventional, for the reader realizes the seriousness of altering the continuity and homogeneity of conductors in a thermoelectric circuit.*

Fig. 16 represents a simple thermoelectric circuit of two dissimilar materials A and B, in which a thermal emf. is being produced because some of the heat entering the system of conductors at the hotter junction *can* be converted into an electro*motive* force (capable of operating an instrument) just so long as there is a colder junction. This does not mean that all of the heat entering the system leaves the

*It really requires a good deal of self-discipline to refrain from cutting and re-uniting wires and doing other simple things which we do every day, without the least hesitation, to almost every other circuit in the plant, or at home, or in the car lighting and ignition systems, etc. But on the other hand, it does not require expertness to do these things correctly—as will be shown in the next section.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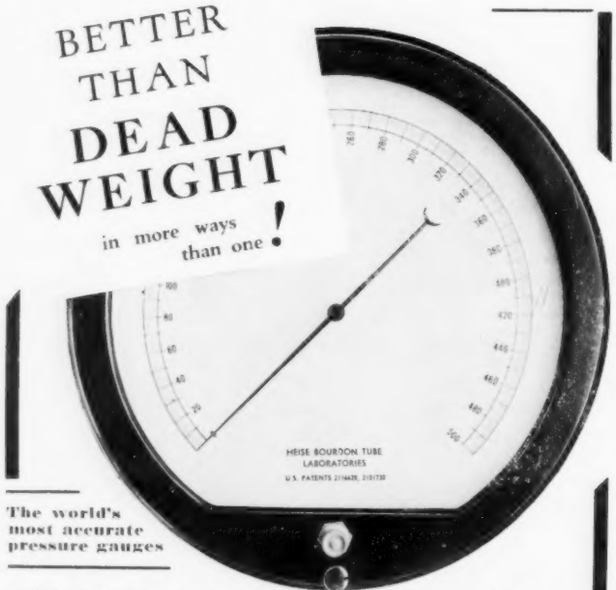

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system at the colder junction. Most of it is wasted by ordinary conduction and radiation. Some of it is actually given out by the colder junction, so that if we packed this colder junction in an ideal asbestos blanket, it would quickly get warmer and before we suspected anything there would only be nine-tenths of the initial temperature difference. (The practical "moral" may be left to the reader.)

At this point it is a temptation to say "And, of course, the remainder of the heat taken in at the hotter junction is dissipated by radiation *from* the conductors because of the Thomson effects *along* the conductors." Not only is this false from a theoretical standpoint but it is contradicted by the hard fact that some materials have positive Thomson coefficients, others have negative Thomson coefficients and still others display no measurable Thomson effects at all. A truer picture may be obtained by considering the Fig. 16 circuit (especially the doughnut physical form of Fig. 9) as *two* heat engines: a simple one in which heat travels horizontally with temperature; and a peculiar one in which heat travels vertically across the temperature *gradient* of the first engine but of course from a hotter to a colder region. *Neither of these thermoelectric engines can exist without the other.* In starting to describe the Fig. 16 circuit, it would have been correct (though unusual) to mention first the "Thomson effects engine" instead of the "Peltier effects engine." The analogy of the right-hand rule* suggests itself—and it is useful, but there is a significant difference: the laws of the electromagnetic field are established and invariable relations, whereas the vertical temperature difference in the "Thomson effects engine" part of the doughnut has as many relations to the horizontal temperature gradients in the upper and lower conductors as there are pairs of actual materials—actual *substances*—with individual properties.

Utterly false, therefore, is the old "law," still taught in some places, still found in discussions printed in recent years, that the Thomson effect *in itself* is the kind of reversible effect which makes possible a thermoelectric engine. The old theory predicted emf's in all conductors, always from cold to hot (and more recently the reason was given as the greater density of the electron gas in the colder part) so that, by utilizing the converse, it would be possible to use a plain, *junctionless,* ring as a thermoelectric system merely by maintaining the right-hand and left-hand portions at different temperatures to have a horizontal temperature gradient, and, presto!, any thermal energy absorbed at the top would instantly be converted into a thermal emf. capable of doing work at the bottom, provided only that the bottom temperature were lower than the top temperature. Advocates of this old theory do not say left and right, top and bottom. They say junctions AB and BA, and conductors A and B. But if that old theory were valid, A and B might as well be made of the same actual substance, without junctions: one homogeneous doughnut.

Thomson emf's are realities, which cause errors in actual thermoelectric circuits where conductors are allowed to become inhomogeneous. The real Thomson coefficients are of the order of microvolts per degree—the same order of magnitude as the utilized total thermal emf's. Therefore the errors are frequently serious. But the old theory, postulating a definite general relation of electro*motive* force to temperature gradients, has little to do with these real Thomson emf's. No less an authority than Dr. W. F. Roeser, of the National Bureau of Standards, has recently† put the final settlement of the question into a strong statement which he calls "The Law of the Homogeneous Circuit." Here it is:

> "An electric current cannot be sustained in a circuit of a single homogeneous metal, however varying in section, by the application of heat alone."

This means that we need not dread temperature gradients along homogeneous conductors. It also implies, "No

*Of the magnetic field associated with a wire in which a direct current flows.

†W. F. Roeser. Thermoelectric Thermometry. *Journal of Applied Physics,* Vol. 11, June 1940, pages 388-407.

junctions, no thermal emf's." The two Thomson emf's and the two Peltier emf's are indissolubly associated in any actual thermoelectric circuit of two actual materials, whatever their independent values may be.

Let us return to the consideration of the quantities of heat entering and leaving the simple thermoelectric circuit (Fig. 16). No material is a perfect conductor of electricity at ordinary temperatures. The current flowing in the circuit by reason of the thermal emf. tends to heat the entire circuit—hotter junction, colder junction and all intermediate sections. In some pyrometer installations, this Joule heat may be a serious source of error when a "contact" junction (bad weld) is heated. Otherwise it seldom is an important one, for electrical insulating materials are imperfect as heat insulators. Its importance arises from two facts: (1) Being irreversible, it must be disposed of; (2) It masks the heating and cooling effects of the individual Peltier emf's and Thomson emf's. (There goes all hope of inventing a reversible thermoelectric engine!)

Consideration of the reversible effects is sometimes useful—especially in precision work where "needle" thermocouples are used on small samples which weigh less than the last ⅛" of the fine wires.

3. Essential Parts

In order to utilize the thermoelectric effect it is generally necessary that the pyrometer outfit include the following:

(a) The thermocouple, inserted where the temperature is to be measured and embodying the measuring junction, which is generally at the tip.

(b) The reference junction, which usually is not one but two connections—between each of the thermocouple wires (or their extension leads) and copper leads or brass terminals.

(c) Some provision for keeping the reference junction at a constant temperature, or (and this is important in industrial plants) some provision for the automatic compensation for variations in reference junction temperature.

(d) An electrical instrument for accurately measuring the comparatively feeble emf.

(e) Various appurtenances and features—some of them essential such as insulation, protection, etc., and some optional, such as styles of tubes, terminal heads, electrical-instrument features, etc.

As good a way as any is to start off with the simplest possible circuit and go through the main points of the millivoltmeter circuit, taking up some questions applicable also to the potentiometer circuit, so that when the latter is reached, only its distinctive features need be dwelt upon.

4. The Simple Pyrometer Circuit (Millivoltmeter)

The simplest form of the thermoelectric circuit was shown in Fig. 16. If both junctions are at the same temperature there will be no emf. Now heat one of the junctions. A current will flow, but we have no means of measuring it—we can't even know that it flows, for no detector is shown.

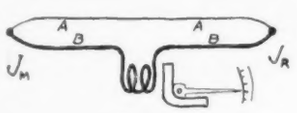

Fig. 17.

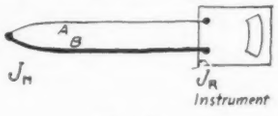

Fig. 18.

In other words, Fig. 16 represented one thermocouple; it did not illustrate a *pyrometer* circuit. Keeping the circuit "simple" by avoiding cutting a conductor, we might try the Fig. 17 scheme, but no one need be an electrical-instrument maker to see that it is impractical.

The next step, then, is to untwist the wires at the cold end and connect them to a millivoltmeter, as shown in Fig. 18. Now we can measure an emf., specifically the potential drop across the instrument terminals. These terminals, by the way, are commonly brass binding posts. New effects are created by the introduction of two additional junctions.

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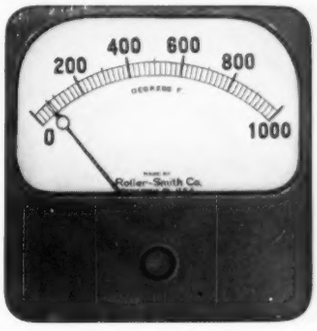

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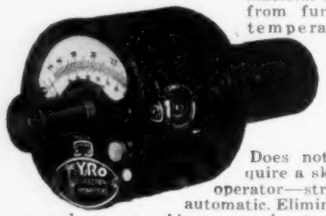

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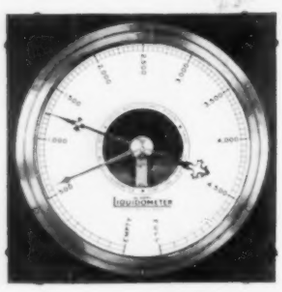

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Thus the simplest measuring circuit differs considerably from that of Fig. 16. In the first place an instrument has been inserted in series, increasing the circuit resistance. Therefore, the current due to the thermal emf. is decreased. Its value in milliamperes is no longer the thermal emf. in millivolts (E) divided by the thermocouple resistance in ohms. It is $E/(R_{Th} + R_{Ins})$. And the potential difference across the instrument terminals is not E but $E \times R_{Ins}/(R_{Th} + R_{Ins})$. This question of resistance ratios will be taken up later. For the moment we assume that the instrument resistance is just right.

In the second place our series instrument is, technically speaking, a milliammeter without a shunt. However, it is used to measure millivoltage. Its calibration in millivolts across its own terminals will remain good if it is treated with the care that any electrical instrument deserves. Its temperature readings will be affected by variations in external circuit resistance. This, too, will be taken up later. We can dismiss it in the case of Fig. 18 where the external circuit is the thermocouple itself—whose resistance for the moment we assume to be constant.

In the third place we have three thermocouples instead of one. Reading clockwise, these are B to A, A to brass, brass to B. Inasmuch as the very first figure in this chapter, and several mentions since then, have implied that most reference junctions are two junctions maintained at the same temperature, the two brass junctions of Fig. 18 can be assumed to introduce no errors. However, it is well to state definitely that the two binding posts have to be maintained at the same temperature. It is even better to generalize this case, and derive a rule applicable to all thermoelectric pyrometer circuits.

The discussions in Sections 1 and 2 have brought out in detail that certain types of circuits will not, and others will, generate thermal emf's; also that a thermoelectric circuit, reduced to its essentials, is symmetrical.

Whatever the point of view from which we consider a thermoelectric circuit, everything comes in pairs: materials, temperatures, temperature gradients, potentials, emf's, and so on. Some pairs are vertical, other horizontal. There is a beautiful symmetry about it—a useful symmetry which, if kept in mind, dispels various "mysteries" and "paradoxes," and enables us to take proper precautions while not wasting time and effort on unnecessary precautions.

What we may call the Rule of Symmetry is but a new name for a series of well-known (but heretofore uncoordinated) directions to users, laws of thermoelectricity, etc. The simplest formal statement of this rule would be a description of the conventional thermoelectric circuit shown in Fig. 16: two junctions, two homogeneous conductors, dissimilar materials, two sets of properties of these materials, two temperatures, two temperature gradients, etc., resulting in two Peltier and Thomson emf's whose algebraic sum is *one* thermal emf. which depends upon the difference between T_M and T_R and upon nothing else.*

If the axiom that equal and opposite effects cancel out is borne in mind, three things can always be done:

1. In making an installation or in using a self-contained outfit the correctness can be verified. See Fig. 19.

2. TO an existing circuit there may be added various features or extras, provided only that each addition does not constitute a source (or sources) of "spurious" or "adventitious" emf's. An alteration will generally be accompanied by a change in total circuit resistance, but this in itself does not involve a change in the *thermal* emf.

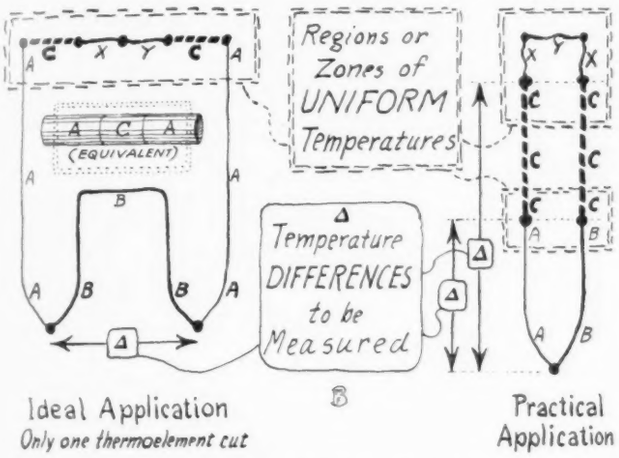
3. FROM the circuit diagram of an existing installation there may be eliminated all features or extras which do not contribute adventitious emf's. There will be no thermal

*It may be elaborated into a recapitulation of the cases where effects can be expected and of the cases where effects are absent, but each elaboration would make it harder to remember. The writer leaves its exact wording to his scientific betters and to clever slogan coiners. The pithiest, most memorable, thermoelectric epigram the writer knows of is Dr. Robert B. Sosman's: "A thermocouple with one junction is no more useful than a scissors with one blade." We need an apothegm of that kind for expressing the rule of symmetry.

emf's if the junctions (or connections) of dissimilar materials in such portions are known to be at the same temperature and if the conductors are known to be homogeneous. In practice, these portions of the entire circuit should be considered, verified and eliminated one by one. The elimination can consist of a pencil line drawn around each feature.

In eliminating portions of circuits it is well to bear junctions in mind. Thus in Fig. 19 we have purposely included "C" in the "Equivalent" although the junctions would all vanish if the temperature were perfectly uniform.

Chief practical use of the law of symmetry is in trouble hunting, particularly in selector-switch installations where it saves time by enabling any unit circuit to be quickly segregated and quickly sketched, and then checked in the least time. The trouble-shooter can determine whether



Applications of the Rule of Symmetry

Fig. 19.

everything is right in that particular circuit, without having to tear down a lot of wiring. Referring to his sketch, he knows that the limits of that circuit are where conductors cross the pencil-line ring. Error-producing "thermals" are quickly located and their causes determined without guesswork.

The law of symmetry should dispel certain hesitations about altering circuits, and replace them by confidence. When an alteration is made, it usually has the effect of adding two or more new junctions. Segregate each pair of additional junctions, think of them as additional thermocouples if the materials are dissimilar, and make sure that the effects are equal and opposite. This done, there will be no thermoelectric alteration; and attention can be centered on the other consequences, such as change of circuit resistance, etc.

The emf. indicated by the millivoltmeter in Fig. 18 is *proportional* to the thermal emf.—less than the true value, of course, on account of circuit resistance, but at any rate we can calibrate the scale in degrees of temperature difference. If such an outfit is used in a thermostated room, we can use it to measure "high" or even "medium" temperatures—depending on the constancy of room temperature (hence of ref.-junction temperature) and on the accuracy required. Note however that this simplest measuring outfit (a pair of thermoelements directly attached to a millivoltmeter) is used also for precision measurements of high temperatures in laboratories—but only when the millivoltmeter embodies automatic compensation for reference-junction temperature (as discussed in the next section).

It is seldom possible, however, to realize the simplicity of the Fig. 18 pyrometer which consists of a pair of thermoelements directly attached to the millivoltmeter binding posts. In permanent installations, we can't put an instrument right at the terminal head of a thermocouple. An actual circuit — not an ideal one — means "wiring" — it means a circuit in which the resistance of some portions

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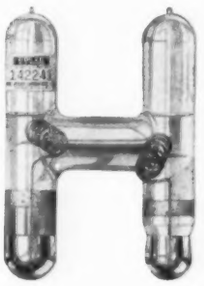

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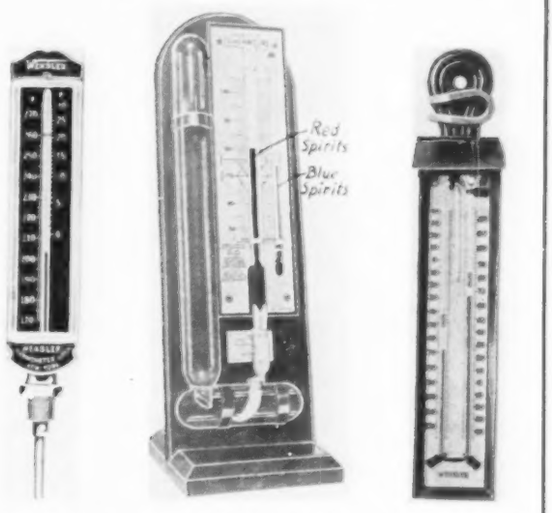

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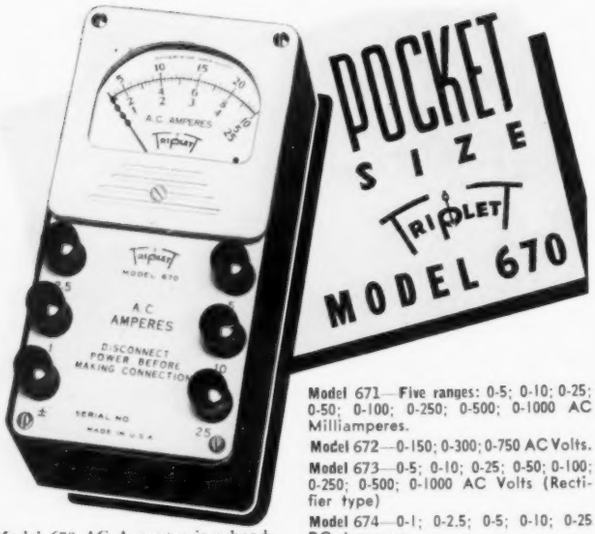

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will vary uncontrollably (poor contacts, corroded wires, variable immersion of thermocouple, "resistance thermometer effect," etc.) The first answer is to introduce a fixed or controllable resistance so much higher than the rest of the circuit—where variations occur—that these variations

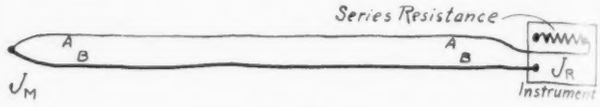

Fig. 20.

will become negligible. Fig. 20 shows the idea—a *ballast* or *series* resistance. It usually is made of manganin, which has a negligible temperature coefficient. (There are other methods, discussed below.) Note that in order not to violate the law of symmetry, this apparently simple insertion of a resistor necessitates at least three additional connections.

In practice we want to save money by running copper leads from the furnace to a remote instrument. This modification is shown in Fig. 21. But now we have seriously affected our circuit. Here is why:

A long copper wire acts as a resistance thermometer. Therefore we must make the series resistance still higher. Secondly, we must do something about the cold junction

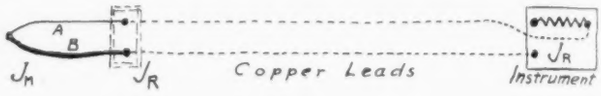

Fig. 21.

temperature, because the only current we are interested in (the one which deflects the millivoltmeter coil) is produced by the *difference* between the temperature of the measuring junction and that of the reference junction. If the reference junction is at the terminal head of the thermocouple tube, the heat radiated by the furnace in which the thermocouple is installed may bring up the temperature of this junction from room temperature to several hundred degrees, introducing serious errors. One way to solve this difficulty is simply to lengthen the couple so that its outer end will be away from the furnace. This need not involve employing *longer* pairs of perfectly homogeneous *thermocouple* wires, which would be expensive in the case of rare-metal couples.

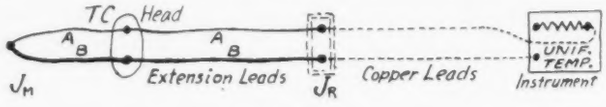

Fig. 22.

The same effect is achieved by connecting to the terminal head special homogeneous flexible conductors serving to *extend* the couple so that the reference junction may be properly handled. For base-metal couples these pairs of conductors may be made of the *same two materials* as the couples, but in the form of insulated stranded cables for convenience. The obvious designation for such cables or leads is *extension leads*. Fig. 22 shows one circuit thus obtained. The reference junction now consists of the two connections of the extension leads to the copper leads, and it may be located where its temperature can readily be kept constant and *known*.

When leads are of materials *different* from those of the thermocouple materials, additional Peltier emf's and additional Thomson emf's are set up. This is inevitable, for we have in effect another pair of thermocouples. In the case of rare-metal couples, extension leads can be made of pairs of inexpensive materials, the temperature-emf. relation of which is practically the same as that of the couple. Such leads are called *compensating* leads. Their purpose is to counteract the intermediate-junction emf. at the terminal head and set up an emf. at a point away from the furnace,

moving the cold junction" as do extension leads made of the same materials as the couple. Since their chemical compositions differ from those of the couples, they are not true extension leads and their two connections to the rare-metal wires must be kept at the same temperature.

A typical compensating-lead circuit is shown in Fig. 23: The instrument contains not only the series resistance but the reference junction and also a mechanical or electrical

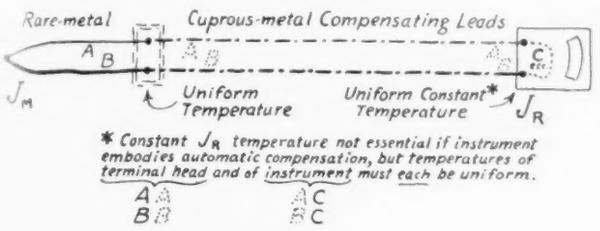

Fig. 23.

arrangement which obviates the need of keeping the reference junction at a constant temperature (see below under "Reference Junction Compensation"). Instead of having the reference junction half way between the furnace and the indicator, it is removed, all the way up to—and inside—the instrument case.

Extension leads and compensating leads are being used in various ingenious ways. There is no space to discuss the many interesting possibilities, but Fig. 24 shows how for

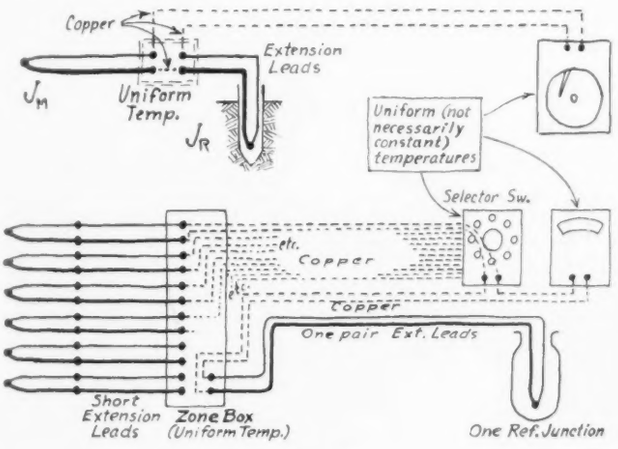

Fig. 24.

example the cold junction may be made to consist (physically) of *one* junction. This is of great advantage in multi-switch installations—one indicator connected to a number of thermocouples. The electrical problems of such circuits have to be worked out, but in many recommended installations they have been worked out by the manufacturer, so that as far as the user is concerned the elementary or unit circuit is as simple as it looks in the figure. (Compare Fig. 18.)

5. The Question of Instrument Resistance

1. A thermocouple develops a feeble emf. (See Chart I, page 317). Hence the need of a sensitive instrument.

2. Pointer deflection depends on torque. Torque depends on ampere-turns in the moving coil. It is a matter of *current* here, because the emf. is definitely limited.

3. The lower the total resistance, the higher the current available for the moving coil. But——

4. With a low-resistance instrument, variations in line resistance produce incorrect temperature indications—and on the other hand, introducing a manganin series resistance of several hundred ohms "eats up millivolts," reducing the emf. available for conversion into ampere-turns.

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Actual figures (from a discussion published by one manufacturer) are now given for two circuits:

	Rare-metal	*Base-metal*
Resistance of thermocouple when cold	2 ohms.	0.1 ohm.
Probable variation of thermocouple resistance due to insertion to different depths and into furnaces at different temperatures.	1 ohm.	0.01 ohm.
Resistance of copper leads	1 ohm.	0.25 ohm.
Resistance of copper coil in millivoltmeter	24 ohms.	2 ohms.
Probable change in resistance of leads and coil due to change in atmospheric temperature	1 ohm.	0.09 ohm.
Probable consequent total change in circuit resistance	2 ohms.	0.1 ohm.
Minimum total resistance by addition of a manganin series resistance in order that above change in resistance does not exceed 1% of the total resistance	200 ohms.	10 ohms.
Emf. of thermocouples at 1800°F.	10 millivolts	40 millivolts
Current flowing in moving coil generating the torque (milliamperes)	$\frac{10}{200} = 0.05$ m.a.	$\frac{40}{10} = 4$ m.a.

The "amperage" of the base-metal couple circuit is eighty times that with the rare-metal couple. (It is not quite right to compare the resistance relations of rare and base metal both at 1800°F. In practice the actual torque will only be thirty to forty times as large.) Here we must consider the practical problem of making use of the amperage while obeying Ohm's Law:

Thick wire, few turns. Low Resistance.

Thin wire, many turns. High Resistance

Say we have a current of exactly one ampere passing around a coil four times, through a thick wire whose resistance is one ohm. We can get the same torque in another coil, with only one-quarter of an ampere, if we use sixteen turns. But this would assume that the two coil resistances are equal. If we cut down the diameter of the wire one-half, we can get the sixteen turns, which will have the same cross-sectional area and the same weight. But unless we use a different wire material the resistance of each turn will be four times as high, and the total resistance of the coil will be sixteen times as high. Therefore, with the same emf. of one volt, we will have only one-sixteenth of an ampere passing through it, and we can only obtain one-fourth of the torque.

This electrical dilemma is complicated by difficult problems of practical instrument-making in the case of high-resistance instruments in which the available torque is extremely small: Friction then becomes so important a factor to be conquered that in general we find that the high-resistance instruments on the market are of the vertical-coil type and only low-resistance indicators have horizontal coils. Ruggedness is realized with low-resistance (high-torque) indicators more easily than with high-resistance instruments—other things being equal.

This does not mean that high-resistance *industrial* instruments are delicate. Witness the following quotation: "As proof of what instruments so constructed will stand in the way of rough handling, we ship them without clamping the moving system. The handling they receive in use is gentle compared with what they receive during shipment."

Inasmuch as the ideal proportions of the various resistances in a pyrometer circuit are unattainable, each manufacturer has presumably worked out the optimum proportions for circuits consisting of standardized thermocouples, extension leads, and millivoltmeter type indicators or recorders.

A few additional notes on this subject:

(1) Chromel, alumel, constantan, nichrome and platinum-rhodium alloys have low temperature coefficients of resistivity: iron, copper and platinum have high coefficients.

(2) Platinum and alloys have a high resistance compared with copper. Copper leads are not often used in rare-metal couple installations where complete compensation is not embodied in the instruments.

(3) A properly-designed high-resistance instrument of *best grade* is more rugged and more reliable than the low-resistance horizontal-coil instruments. Some high-resistance pyrometer instruments are not rugged and can't stand vibrations; some low-resistance *pyrometer* instruments are not comparable with corresponding electrical measuring instruments manufactured for electrical measurement purposes.

(4) The resistance of every instrument should be plainly marked on its name plate or scale.

6. Line Resistance Compensation

It has been shown that one way to minimize errors caused by fluctuations in line resistance due to temperature fluctuations is to use high-resistance instruments. It also is often advisable to take care of *changes* in the line resistance which occur in service. One obvious way is to measure the line resistance from time to time with a Wheatstone bridge, and to correct faulty conditions as they are thus detected. This method is used in many plants where, by means of portable test sets, lines are frequently inspected and kept in good condition, making it possible to use low-resistance instruments year after year rather satisfactorily.

This, however, is not "compensation." There are two methods of compensation, both manual:

1. Using an adjustable series resistance. An instrument made up with such a rheostat is calibrated for a new installation of thermocouple and leads, with the resistance at its *maximum* value. The adjustable resistance is reduced from time to time as the line resistance increases—such increase being determined by a portable test set.

2. The Harrison-Foote method. This obviates the need of a separate test set by a built-in arrangement of resistances, one of which is adjustable and in series with the line and moving coil, and is set at its maximum value when the instrument is calibrated. The arrangement is such that when the instrument is used for the first time the series resistance can be adjusted by seeing that the reading is the same with a push button (or key) open or closed; and thereafter, as the line resistance changes, this series resistance is changed—the adjustment being conveniently made the same way by seeing that the readings are the same with the key open or closed. This device is useful for multiple installations of different line resistance, as many series rheostats being used as there are thermocouples, and each being adjusted from time to time in the manner described.

7. Reference Junction Compensation

Any uncompensated variation in the reference temperature will cause a corresponding error in the indication of the measuring junction temperature. As with the line resistance variation (which is less serious) we can do two things: take care of the reference junction by keeping it at a constant temperature, or let it fluctuate but compensate for variations.

To keep the reference junction at a constant temperature it must be moved away from the terminal head of the mounting (by extending the thermocouple as explained above) to where we can locate it at will. There are several ways of keeping it within a few degrees' variation. For checking and testing purposes in the plant, as well as for scientific work in the laboratory, a thermos bottle filled with cracked ice is best, for it gives the ice-point reference within a fraction of a degree and makes possible the most accurate work. For some installations the cold end may be buried—down a pointed pipe driven 10 ft. into the ground. Thermostat-controlled boxes are also in use.

None of these methods, however, is "compensation." There are two distinct methods of compensation—manual or automatic.

(1) Manual compensation: The circuit is opened, the pointer or pen-arm is set to read the temperature of the reference junction, which in the simplest case will be that of the instrument, and the circuit closed for work. The instrument is at the room temperature (except when carelessly located) but in order to eliminate guesswork a simple

thermometer may be embodied in the instrument, as illustrated in Figs. 25 and 26, the former showing a device which obviates close examination of the scale.

Fig. 25. Bimetallic coil thermometer by means of which millivoltmeter pointer is initially set. *(Brown Instrument Company).*

Fig. 26. To aid in setting for temperature of cold junction located in instrument case, some makers supply, on request, a thermometer such as the one shown. *(Taylor Instrument Companies).*

(2) Automatic compensation is obtained in many different ways in the laboratory, but in the plant there are three important methods: (a) mechanical, (b) magnetic and (c) electrical.

(a) Mechanical Device

Fig. 25 suggests a simple mechanical automatic method: interposing a bimetallic spiral between the moving coil (of the usual type of electrical instrument) and the pointer or pen-arm, in such manner that with the circuit open the reading will be the reference-junction temperature. This method, introduced in the U. S. by Bristol, is used in several makes, and compensates not only for cold junction variations but also for the temperature coefficient of the instrument itself, which results mainly from the change in the strength of the spring and the resistance of the copper moving coil. It is of course impossible for the bimetallic coil to compensate *exactly* for both, because while the cold junction error does not depend on the temperature being measured, the resistance error is closely proportional thereto.

(b) Magnetic Shunt

The magnetic shunt automatic method is ingenious: just a small block of iron on a thermostat spring which brings it closer to or farther from the poles of the instrument magnet as the temperature varies, affecting the strength of the field and hence the effective torque of the coil.

(c) Electrical

Unlike the electrical method of compensation for line resistance, which requires manual operation, the electrical method for reference junction temperature compensation is fully automatic. The ideal method would be to insert a series resistor made of a material having a *negative* temperature coefficient of resistivity. Such materials are rare, not commercially standardized and otherwise impractical to use at present. However, a fair equivalent of this future method is to use in an auxiliary circuit a material having a high temperature coefficient of resistivity. Fig. 27 is a diagram of the Foxboro bridge compensator. Three sections of this bridge are resistances composed of materials of constant resistance. The fourth section is of material having a high temperature coefficient. The resistance changes of this compensating coil, which is located in the reference-junction zone, alter the relationship between the sections of the bridge, causing the current from a dry cell battery, connected across the bridge, to correct the thermocouple emf. electrically in accordance with the changes of the cold junction. (This temperature-responsive coil and the cold end are both located at the instrument.) A rheostat in the battery circuit is used periodically to adjust the battery current, and a switch connection permits checking the rheostat adjustment, using the pyrometer millivoltmeter to measure the battery adjustment to a check point on the scale.

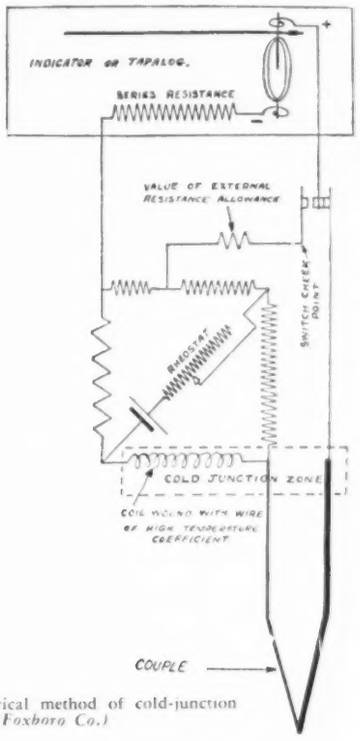


Fig. 27. Electrical method of cold-junction compensation *(Foxboro Co.)*

With or without cold-junction compensation it is always necessary to maintain all connections which make up the reference junction, at the same temperature.

When an instrument embodying automatic compensation is exposed to radiation from a furnace, the terminals, if they are not enclosed in the instrument case, may be at a much higher temperature than the inside of the instrument where the automatic compensator is installed.

This same source of error will give the same trouble if the reference junction is not located at the instrument.

The largest errors, in both cases, will occur if one side of the instrument is at a higher temperature than the other side, for the rule of symmetry is badly violated.

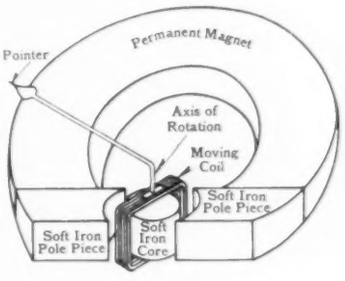


Fig. 28. The essentials of the most widespread form of permanent-magnet moving coil measuring element. *(Westinghouse Elec. & Mfg. Co.)*

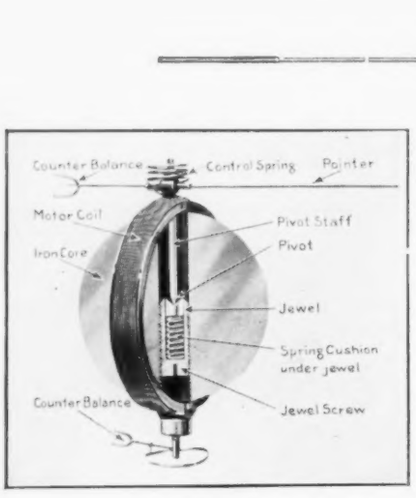
8. Examples of Millivoltmeter Pyrometers

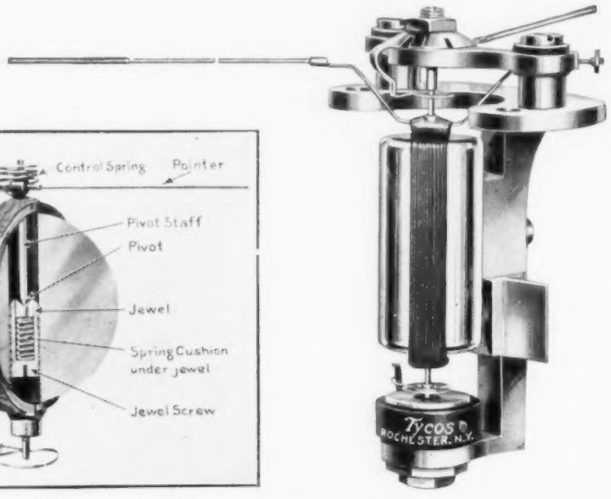
Preceding sections have brought to light some instrument characteristics and their influence, but without describing the instruments. In thermoelectric pyrometry the millivoltmeters are of the electromagnetic type known as permanent-magnet moving-coil. Fig. 28 shows the general

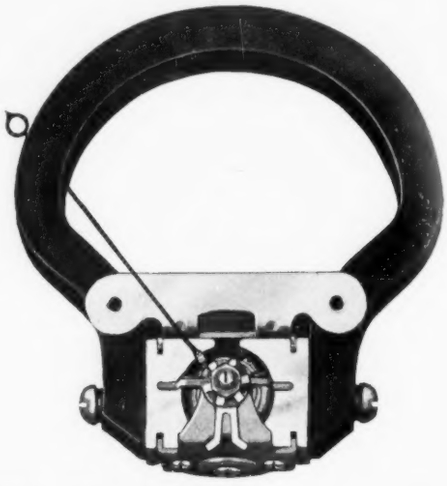
arrangement, and Figs. 29-31 show examples, of what is commonly called the "movement"—the assembly which performs the same function of measuring by deflection whether it is embodied in a voltmeter or an ammeter (or in a tachometer, a flowmeter, a pyrometer, etc. . . .)

The names ammeter, voltmeter and wattmeter signify different *instrument circuits* including measuring element plus associated shunts, resistors, etc. (The wattmeter element, however, has a field coil instead of a permanent magnet, so we need not consider it here.) The names tachometer, pyrometer, etc., imply applications—external circuits—but generally refer to electrical instruments whose *scales* are marked and graduated for special purposes.

More than a hundred companies manufacture permanent-magnet moving-coil millivoltmeters — of all grades from the cheap mass-production indicators on an automobile instrument board to the laboratory standards selling for more than the price of a small automobile. The grades of the millivoltmeter movements incorporated into industrial pyrometers do not extend to these extremes. The industrial "miniature" millivoltmeters are immensely superior to the automobile instruments of corresponding sizes. We particularly mention these miniature pyrometer instruments because they are the only ones that can and may be used with different couples by merely changing the series resistance. In other words, when the emf. deviations from







TWO "MOVEMENTS" AND A "MEASURING ELEMENT" OF TYPICAL MILLIVOLTMETERS

Fig. 29. Cut-away view of spring-supported vertical-shaft movement. (*The Foxboro Co.*)

Fig. 30. Close up of conventional double-pivot movement of millivoltmeter. (*Taylor Instrument Companies*)

Fig. 31. Complete measuring element of a horizontal-shaft instrument. (*Roller-Smith Co.*)

Thus a moving-coil type *measuring element*, such as the one shown in Fig. 31, could be used to measure emf. or current. To measure emf. it is put in a case with a manganin resistor in series; and its scale is calibrated in millivolts across the instrument binding-posts for a given value of external-circuit resistance. For its scale to indicate thermocouple temperature, there are two principal modifications:

1. The instrument having been connected to a given type and length of couple having a given cold resistance, the scale is calibrated to read measuring-junction temperatures with the reference junction at a given temperature (*either* 32°F. or say 75°F.). This original calibration will usually be based on a definite "thermocouple immersion," i. e., a definite ratio of double-wire length at measuring-junction temperature to double-wire length at room temperature, hence a definite variable external-circuit resistance.

2. The usual instrument bimetal compensator (which corrects only for the instrument temperature) is replaced or supplemented by one which corrects for reference-junction temperature as explained in Section 7. (Note however that this may be purposely omitted in some high-grade instruments, the ice-point reference being used.)

The result of these two modifications is a thermoelectric pyrometer. If it is to be used with couples and leads whose resistance will vary uncontrollably, it may be further equipped with a line-resistance compensator. Other optional features may be added. The main point to bear in mind, however, is that the scale of the millivoltmeter now conforms to the temperature-emf. relation of *one type* of thermocouple. Reference to Chart I (page 317) will show that the curves of different couples differ not only in slope but in linearity. Theoretically, a pyrometer instrument cannot be "universal" and "accurate." Actually, the situation modifies the theory. Here is why:

a straight-line relation are actually smaller than the "readability" of a small instrument, there are no *practical* reasons against interchanging couples—provided only that the user will not use a magnifying glass to read closer than about 3% of the scale range.

By the same token, a large millivoltmeter with anti-parallax mirror, which can easily be read to 0.2% of its scale range, may be made up with several scales, each calibrated for one type of thermocouple. The mirror-scale feature generally signifies a laboratory grade instrument, but a laboratory grade millivoltmeter designed for checking various couples in a plant will certainly not be designed to sell for the price of an automobile.

One more pertinent fact: The high-grade movements are made by four or five firms, but they are incorporated in the pyrometers of forty or fifty companies which manufacture temperature instruments rather than electrical instruments. There are even large "electrical-*and*-temperature" firms which use certain types of highly-developed millivoltmeter movements (other than their own) in some of their own pyrometer outfits.

This situation, of distinct interest to industrial users, is not likely to change for twenty years after this book is published. Its word-picture in the preceding paragraphs obviates the need of including several pages of figures and captions. Figs. 32 to 38 are designed, therefore, to bring out the influence of applications rather than the details of instrument constructions.

For the plant instrument department's calibrating room, a high-grade millivoltmeter, though not as accurate as a potentiometer (see Section 9) may be preferred to the latter for reasons of convenience, etc., particularly in a plant lacking *constant*-temperature furnaces—because such a millivoltmeter can follow small temperature variations.

Fig. 32 shows a millivoltmeter with mirror-scale, cobalt magnet, electrostatic and magnetic shielding and other laboratory features, which nevertheless is portable and does not require critical leveling adjustment. Its coil resistance,

Fig. 32. Portable laboratory millivoltmeter pyrometer, the electrical "movement" of which is made by the Weston Electrical Instrument Corp. This is a relatively large (8" wide) model. (*The Bristol Co.*)

116 ohms, is designed for 20 ohms per millivolt. It is available in double-range models, with its 5½" scales calibrated in millivolts or for the temperature-emf. curves of standardized thermocouples.

Horizontal-shaft instruments, though seldom made up for the highest precision, can be constructed as portable testers. The one shown in Fig. 33 has its measuring element spring-suspended within the outer case.

Fig. 33. "Shock-proof" laboratory grade millivoltmeter in which the coil pivots and jewels are vibration-resistant and the entire measuring element spring-suspended within the outer case. (*Illinois Testing Laboratories.*)

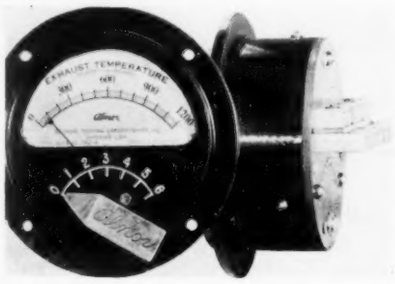


Fig. 34. Diesel-engine exhaust millivoltmeter pyrometer for flush mounting in instrument board of vehicle, boat or small plant. (*Illinois Testing Laboratories.*)

Obviously different are the characteristics desired in a multiple-thermocouple pyrometer for the small diesel engines of trucks, motor-boats, buses, construction-job lighting plants, etc. Here small size is the first requirement and close readings secondary. Fig. 34 shows a pyrometer and a six-point selector switch (up to twelve points available) all contained in a case of which the extreme diameter is four inches. Note that the contact areas (at the right-hand side) for connecting the leads have been made as large as possible within the available space.

Somewhere between these extremes of requirements are those of "general testing of transformrs, ovens, appliances, etc." The outfit shown in Fig. 35 was brought out in 1940

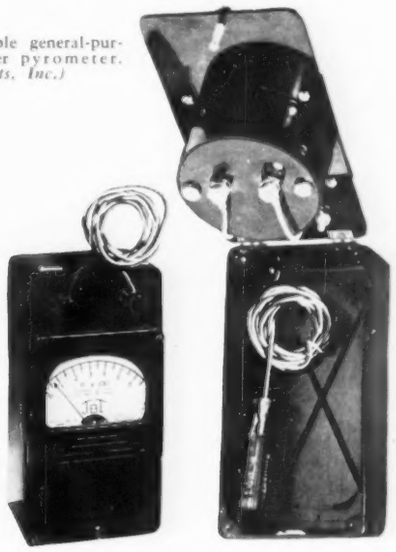


Fig. 35. Portable general-purpose millivoltmeter pyrometer. (*J-B-T Instruments, Inc.*)

to meet such requirements and others around the plant. The millivoltmeter has a 2⅜" scale graduated for a 42" flexible iron-constantan thermocouple with small tip, which is coiled up in the coat-pocket-size outer case.

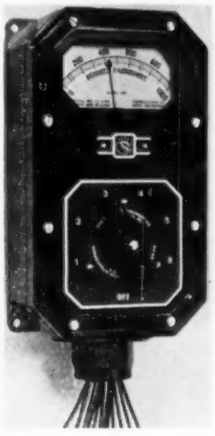


Fig. 36. Diesel-engine exhaust millivoltmeter pyrometer with multiple switch mounted in separate compartment. (*Brown Instrument Co.*)

Fig. 37. Example of the "horizontal edgewise" design of millivoltmeter. The vertical-shaft measuring element is aperiodically damped. Scale length, 6 inches. (*Illinois Testing Laboratories.*)

Two multiple-circuit switchboard millivoltmeters are shown in Figs. 36 and 37; the first has a horizontal-shaft movement; the second has a vertical-shaft movement but note that it differs from the Fig. 32 bench instrument in its "edgewise" construction.

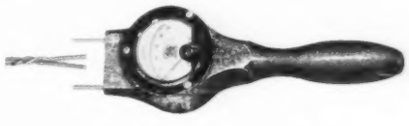


Fig. 38. The "Hold Heet Pyrometer Lance" (*Russell Electric Co.*)

Where light weight is the chief requirement, as in the "lance," prod," "sword" and other portable pyrometers, miniature instruments (as in Fig. 38) do much to extend the scope of pyrometry. This is one reason why millivoltmeters outnumber potentiometers by three to one or more.

9. The Potentiometer Circuit

(See also "The Millivoltmeter Circuit" because the subjects applicable to both types of circuits will not be repeated here).

For precision work the potentiometer is preferable to the millivoltmeter. First, it may be more sensitive: its scale range may be as short as desired. But even more important, the potentiometer method makes it possible to measure the emf. developed by the thermocouple, regardless of variations in circuit resistance, length of leads, and certain other electrical conditions which may affect the reliability of millivoltmeter readings, especially after months of severe industrial service.

The potentiometer circuit is one in which an unknown emf. is opposed to a known emf., standardized by means of a standard cell, and resistances adjusted until there is *a negligible flow of current at the moment of measuring.* (This applies only to the true null-method potentiometer. In a deflection potentiometer a part of the emf. is unbalanced, and measured in the usual way by its effect on a moving coil.)

Now consider what this means in thermoelectric pyrometry. Say we have a 30" rare-metal couple. We want to measure the *uniform* temperature of a furnace. A millivoltmeter may read 20°F. higher when the thermocouple is immersed a few inches than when it is immersed all the way—the reason being the increased resistance of the thercocouple wires which form part of the circuit. With a null-method potentiometer there can be no difference in the two indications.

It must not be inferred that potentiometer pyrometers will ultimately drive out millivoltmeters. The latter, in their convenient and satisfactorily accurate modern forms, serve an increasing number of applications in industry where the greater initial cost of the potentiometer is not justified. However, for all applications where variations in external circuit resistance cannot be avoided, and where accuracy to 1% of the instrument scale range is desired, the potentiometer should be adopted.

Electrically, there are three types: the true potentiometer, the semi-potentiometer and the deflection potentiometer.

Morphologically, too, there are three types: bench (with or without galvanometer and other appurtenances), portable, and switchboard.

Industrially, there are two types: manually-balanced and self-balancing. Recorders and controllers must be self-balancing.

Apart from these classifications there is still another, based on the ohmic value of the potentiometer resistance proper. This corresponds in order of magnitude to that of the measured emf's, so that for thermoelectric pyrometry where we seldom deal with more than a tenth of a volt we may use what are known as "low-resistance" potentiometers. The dividing lines are not sharp; but "low" generally means 500 ohms or less and "high" 2000 ohms or more.

The importance of these various classifications will be brought out later. First, there will be described the simple potentiometer circuit and its development into that of the typical industrial pyrometer with compensation, etc. For this purpose a set of six diagrams prepared by the Leeds & Northrup Co. will be used:

Fig. 39 shows the wiring of the potentiometer in its simplest form. The thermocouple is at H, with its polarity as shown by the symbols + and —. It is connected with the main circuit of the potentiometer at the fixed point D and the movable point G.

A current from the dry cell BA is constantly flowing through the main circuit, ABCDGEF. The section DGE of this circuit is a slide wire. The temperature scale is fixed to this slide wire. The current from BA as it flows through DGE sets up a difference in potential between D and E. There will also be a difference in potential between D and all other points on the slide wire. The polarity of this is in opposition to the polarity of the emf, of thermocouple which connects into the potentiometer at D and at G. By moving G along the slide wire a point is found where the potential between D and G in the slide wire is just equal to the emf. generated by the thermocouple. A galvanometer in the thermocouple circuit indicates when the balance point is reached, since at this point the galvanometer needle will show no deflection.

The potential in the slide wire will vary with the current flowing through it from BA and a means for standardizing this is provided. S.C., Fig. 40 is a standard cell whose voltage is constant. It is connected to the potentiometer circuit at two points D and F by closing the contact shown between S. C. and Galv., whenever the potentiometer

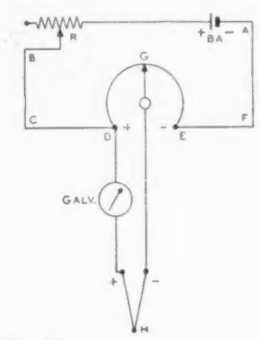


Fig. 39.

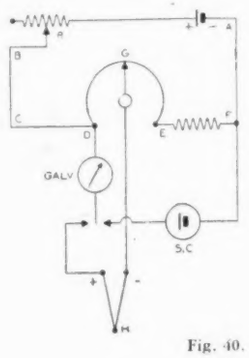


Fig. 40.

current is to be standardized. The galvanometer is then in series with S.C. Variable rheostat R is then adjusted until the current flowing is such that, as it flows through the slide wire DGE and the standard resistance EF, the fall in potential between D and F is just equal to the voltage of the standard cell S.C. At this time the galvanometer will indicate a balance in the same way as when it was used with a thermocouple. By this operation the current in the slide wire DGE is standardized periodically after which the standard cell is disconnected and the thermocouple connected by closing the contact shown between Galv. and the + side of H.

Reference-junction Temperature Compensation. The value of the balancing potential is controlled by the position of G. Make D movable as shown in Fig. 41, and the magnitude of the potential DG may be varied either from D or G.

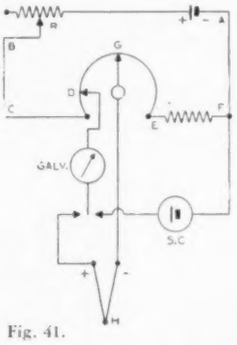


Fig. 41.

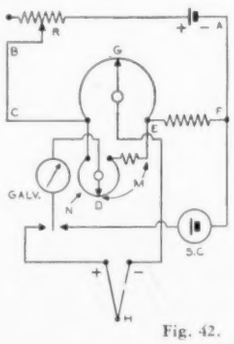


Fig. 42.

This gives a means for compensating for cold junction changes by setting slider D along its scale until it corresponds to the known temperature of the cold junction, and then the potentiometer is balanced by moving slider G. The readings of G will then give the temperature of the hot junction directly.

The same results will be obtained if another slide wire upon which D bears is placed in parallel with the slide wire of G, as shown in Fig. 42. Such a slide wire, with a temperature scale fixed upon it, forms the manually operated cold junction compensator.

It should be noted that the effect of moving contact D is either to increase N and decrease M, or to decrease N and increase M; in other words, the ratio between N and M is

varied. In indicators and recorders employing the automatic cold junction compensator, the ratio of N to M is varied automatically, in the following manner:

Point D. Fig. 43, is mechanically fixed; on one side of D is constant-resistance coil M; on the other side, at or near the cold junction, nickel coil N. Nickel has a high temperature coefficient and the electrical proportions of M and N

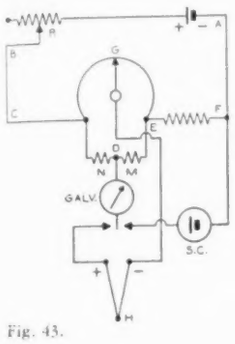


Fig. 43.

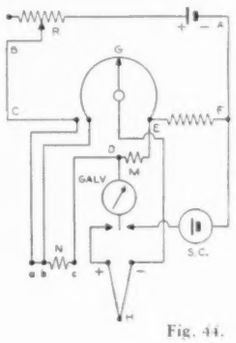


Fig. 44.

are such that the resistance change of N, as it varies with the temperature of the cold junction, has practically the same effect upon the balancing potential between D and G that the movement of the point D has in the hand operated compensator.

Fig. 44 shows a modification to meet the condition where the cold junction is located at some point distant from the measuring instrument.

Factors Bearing on Accuracy

The accuracy attainable with a potentiometer is founded on the balance method and it therefore depends on the electrical equivalents of precision weights. In a bridge, the comparison standard is a set of resistors. In a potentiometer, however, there is (1) an ultimate reference standard: the emf. of the standard cell; (2) a working standard: usually the periodically adjusted emf. from a battery or other convenient source; and finally (3) a means of balancing emf's: the set of resistors.

The reference standard is the emf. from a standard cell, which is a small voltaic cell of the cadmium type and of the H form. There are two makes: Weston Electrical Instrument Corp. (Newark, N. J.) and Eppley Laboratory (Newport, R. I.) Both makes have qualified as the International Practical Standard for the physical embodiment of the International Volt. The emf. of a standard cell is a little over one volt, the exact value being certified (to a few *millionths* of a volt in the laboratory standards, to 0.1 millivolt in the industrial models). The temperature coefficient is negligible in practical work in the plant. Electrical authorities recommend that three laboratory standard cells be owned by each calibration laboratory and that each be sent once a year to the standardizing laboratory.

We have seen in Chapter VII that the resistance thermometer is the most accurate temperature-measuring device because oil-immersed Standard Resistors (and of course good quality precision resistors) are commercially available. The precision of the resistors embodied in potentiometers for thermoelectric pyrometry, however, is largely governed by the total price, size, weight, etc., of the complete instrument. A portable potentiometer must be portable; and a switchboard type automatic self-balancing recorder-controller represents a considerable investment without a single resistor. Now, then, one of the famous high-precision Eppley potentiometers with thermostated motor-stirred oil bath, occupies a small table-top and sells for more than a "de luxe" small car. This is one reason why the easily attainable fourth-decimal accuracy of the potentiometer *method* cannot always be realized in the use of industrial potentiometers for thermoelectric pyrometry.

Moreover, while the moderate-price *bench* potentiometers used in the plant calibrating room can be reasonably (or even wholly) free of adventitious emf's, this is not true of the other two types: the portable potentiometers must be small and light; the switchboard instruments embody such heat sources as electric motors, lamps, electron tubes, etc., as essential parts of otherwise marvelous mechanisms. Most of the inexpensive portable potentiometers, and most of the self-balancing instruments, are somewhat haunted by "ghost currents" or adventitious emf's. Users should spare no effort to keep the many junctions at uniform temperature.

Galvanometers. In laboratory work a galvanometer usually is an instrument in itself. Being designed for utmost sensitivity (10^{-9} amp. is not uncommon) it requires a special suspension and careful leveling. In recent years the increased demand for galvanometers suitable for use in industrial pyrometer department has resulted in radically new designs. These instruments are suitable for use with the bench potentiometers and bridges with which such industrial departments are equipped. Among numerous examples is the self-contained "Spotlight" galvanometer, Fig. 45, in

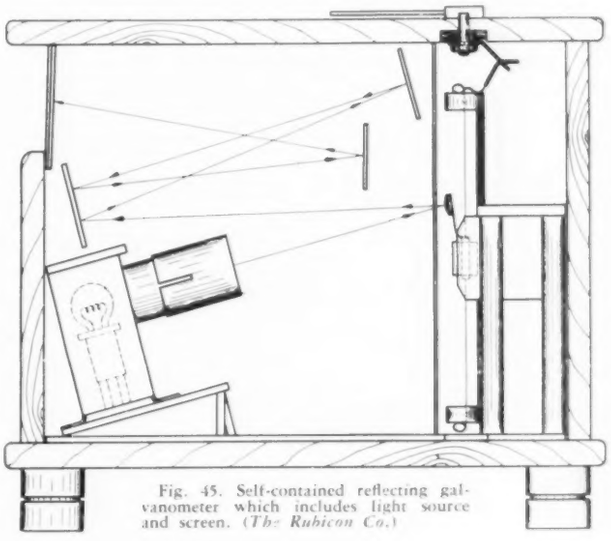


Fig. 45. Self-contained reflecting galvanometer which includes light source and screen. (*The Rubicon Co.*)

which the multiple-internal-reflection principle gives a light path 30" long. The visible indication on the frosted glass is a spot of light with a diametral sharply-focused line. The period is two seconds for microvolt or microampere sensitivities.

In process temperature measurement and control work, however, a galvanometer usually is a seldom-seen component of a self-balancing potentiometer or bridge. Being designed and constructed for switchboard service, it is above all a small and rugged device. When a galvanometer is merely employed as a galvanoscope—as the unbalance-detecting element in the industrial-instrument measuring system of which it forms a part—it does not measure the temperature: its function may be likened to that of a magnifying glass for reading the vernier of a high-grade surveying instrument. However, in some industrial electrical temperature instruments, the element frequently referred to as the "galvanometer" is not only a measuring element but *the* measuring element. Actually, it is a milliammeter, a millivoltmeter, a microammeter or a microvoltmeter—i.e. a calibrated measuring element—most frequently of the permanent-magnet moving-coil type. Note, however, that whereas most measuring elements of this type embodied in ordinary deflection instruments are side-zero, most of them must be zero-center when incorporated in null-method recording or controlling systems. An easily-accessible zeroing knob or screw is provided, but in spite of this provision the galvanometer must be much more stable than a laboratory galvanometer which is under the direct observation of the user.

In addition to smallness, ruggedness and stability, industrial-instrument galvanometers must meet the short-period

requirements of high-speed multiple-point recorders, automatic control systems, etc.

These four attributes characterize the galvanometers produced in quantities for well-known makes of industrial potentiometers. Such galvanometers are the equals of laboratory galvanometers in nearly all properties other than sensitivity. When "galvanometer trouble" is reported by users of elaborate industrial instruments, it generally turns out to be due to faulty incorporation or installation.

From the preceding paragraphs it would appear that all potentiometers must embody a standard cell and a galvanometer. This is not an essential requirement. In some industrial potentiometers there are substitutes which perform the corresponding functions. For example, instead of a standard cell there may be any one of a number of different devices based on the use of regulated voltages or currents. Such devices may be simple arrangements of resistors having utilizable characteristics (the "lamp bridge" is one of them) or they may be elaborate automatic regulators external to the potentiometer. As a rule these substitutes for standard cells serve the same purpose, namely, a reference "standard" of emf.* And instead of a galvanometer there may be a microphone, or there may be an electrical or electronic device characterized by total absence of mechanical movement. In either case the substitute for a galvanometer serves exactly the same purpose, namely, unbalance detection. Therefore, the use of such unbalance detectors does not introduce errors in practical pyrometry.

Semi-potentiometer.—In the semi-potentiometer no current flows at the time when a measurement is performed, but the value of the emf. is obtained from a deflection instrument in the circuit. The thermal emf. is opposed by another emf. from any convenient source such as a battery, and the state of balance indicated by a galvanometer. The opposing emf. (which is then equal to the *thermal* emf. because couple and lead resistance variations play no part) is read on a millivoltmeter. Advantage: no current flowing. Limitation: the accuracy of the deflection instrument—not so much its original accuracy, but its accuracy at the time the measurement is made. Much depends on the user's care, especially when one deflection instrument serves two purposes.

Deflection Potentiometer.—The true null-method requires that no current flow at the moment of measurement. But in order to balance the circuit we require a galvanometer. Let us then call the galvanometer a millivoltmeter or microvoltmeter (which it is) and calibrate its scale in degrees of temperature by referring to the Bureau of Standards' curve for the couple with which the instrument is to be used. We can make the microvoltmeter scale cover a range of ten degrees or even less, with its center at the temperature at which the circuit is balanced. Such, in brief, is the deflection potentiometer.

10. Examples of Manually-balanced Industrial Potentiometers

(Self-balancing potentiometers and bridges will be described under recorders, their mechanisms being emphasized. The following lays stress on the practical pyrometry viewpoint. Fine points of circuits will not be discussed. Beginners to whom even the circuits shown seem difficult are advised to start with what is usually entitled the "Kelvin-Varley Slide" in books on electricity.)

Bench Instruments.

Well-known for a quarter-century, the Leeds & Northrup series "K" potentiometers are slide-wire type, bench form, instruments. The essentials of their circuits were brought out in Figs. 39 to 41. The circuit of "Type K-2" is shown in Fig. 46. This instrument has three ranges: 0-0.016, 0-0.16 and 0-1.6 volts. Note in the lower-center the 200- and 2000-ohm resistors, either of which may be used as damping shunt for whatever galvanometer is used. A structural feature is the absence of plug contacts.

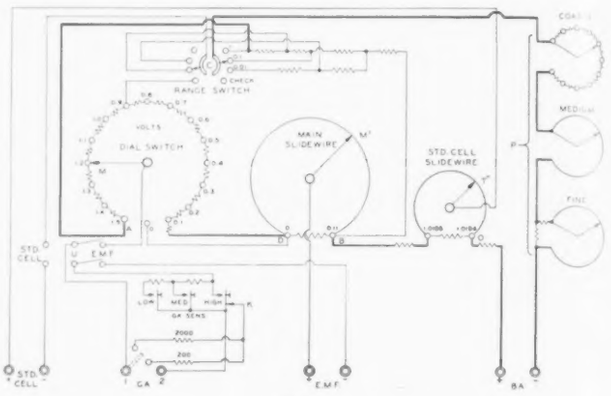


Fig. 46.

A recently brought out laboratory potentiometer embodying special refinements for work with thermocouples is the Rubicon Co.'s three-dial "Type B" which several large industrial temperature instrument manufacturers use for standardizing and calibrating their pyrometers. Among the features of the circuit (Fig. 47) are a new compensation circuit in which only 10% of the "main potentiometer" cur-

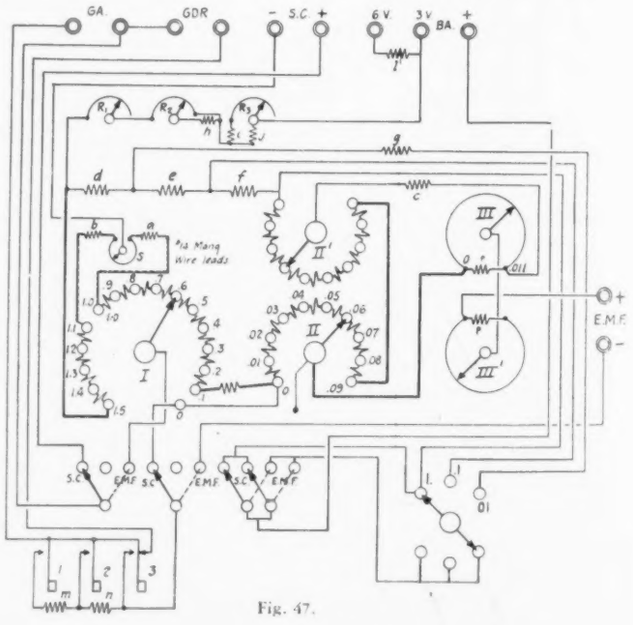


Fig. 47.

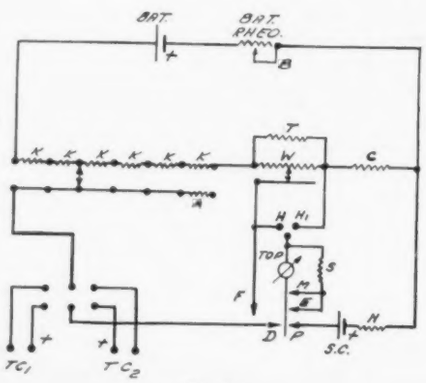


Fig. 48.

*In the popular makes of portable potentiometer pyrometers which embody such "standards," the uncontrollable variations of the "standard" may amount to 0.3% during a single one-minute period of observation. The total uncertainty or variance may be nearly a hundred times greater than that of a portable type standard cell—more than a thousand times greater than that of a laboratory type standard cell. Such substitutes may therefore introduce errors in the measurement of thermocouple emf's.

rent flows through the second dial switch. Spurious emf's are minimized by other features, among them the provision of a second slide wire, electrically identical with the main slide wire, the two being arranged to satisfy the rule of symmetry; also structural features such as beryllium copper binding posts, gold contacts on bronze leaves, etc., as recommended by the National Bureau of Standards.

Portable Potentiometers.

In the lower part of Fig. 48, which is the circuit of the Brown Instrument Co.'s Portable Potentiometer, there is seen a switch for quickly checking a working couple against a plant standard couple. This identifies the chief purpose of the instrument, which includes a standard cell and a galvanometer. Its range is 72 millivolts. The slide-wire scale is graduated in 0.05 millivolts in 1/16" divisions.

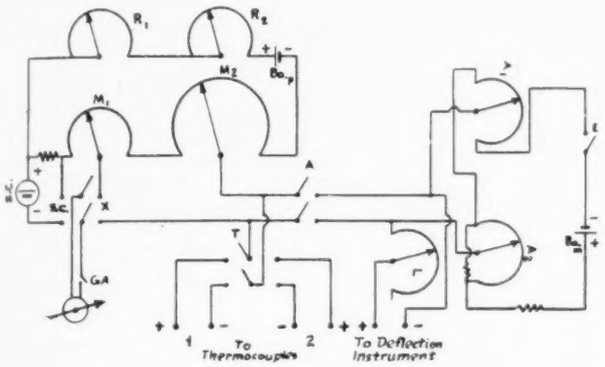


Fig. 49.

The circuit of the Thwing-Albert Instrument Co.'s "Treasure Chest" is shown in Fig. 49. This outfit includes a potentiometer and an auxiliary source of emf. and associated circuit whereby deflection instruments may be calibrated up to 101 millivolts, and resistances of pyrometer circuits measured.

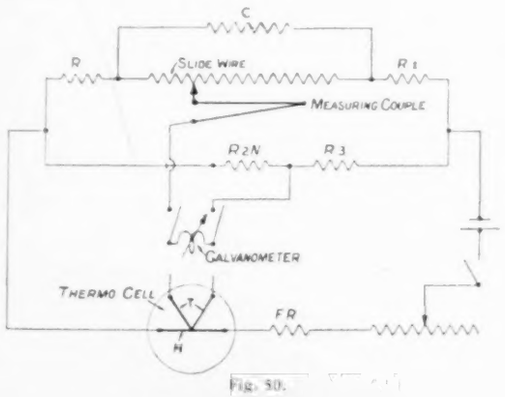


Fig. 50.

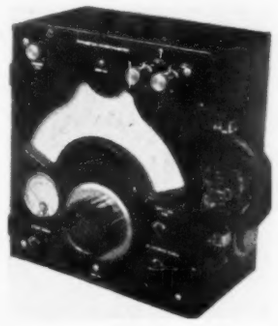


Fig. 51.

Since 1935 the number of makes of portable potentiometers has quadrupled if not quintupled. The new entrants in the field seem to go after "difficult" applications. The Lewis Engineering Co., for example, brought out instruments for aircraft use (Figs. 50 and 51) and for service where severe vibrations are present. As seen in Fig. 50, there is no standard cell: the substitute, known as "Thermo Cell," is a heater and thermocouple in vacuum, having a sharply-inflected curve of heater current to thermocouple emf. whereby a "standard" emf. is available. The "pocket size" instrument shown in Fig. 51 weighs 4 lbs. 10 oz. and requires no leveling.

Fig. 52.

An outside view is shown of the Wheelco Instrument Co.'s portable potentiometer, Fig. 52, because it brings out the unique arrangement of the slide-wire drum. This outfit is a true potentiometer, employing a standard cell. Reference-junction compensation is also embodied.

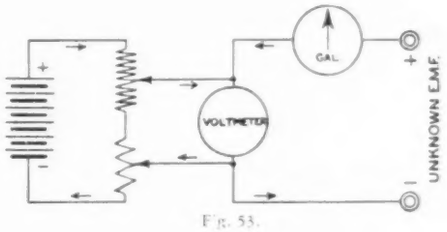


Fig. 53.

A weight-saving idea applicable to the semi-potentiometer, which appears to have been originated by the Sensitive Research Instrument Corp., is to have both a galvanometer and a millivoltmeter (see Section 9) but to have their respective moving elements employ the same magnet. Fig. 53 shows the circuit of that firm's semi-potentiometer, known as the "Rhodes Potentiometer Voltmeter."

Fig. 54.

A portable instrument. Fig. 54, usable as a null-method or as a deflection potentiometer is made by J-B-T Instruments, Inc. In the latter case, of course, it must be used only with the thermocouple for which the deflection scale has been calibrated.

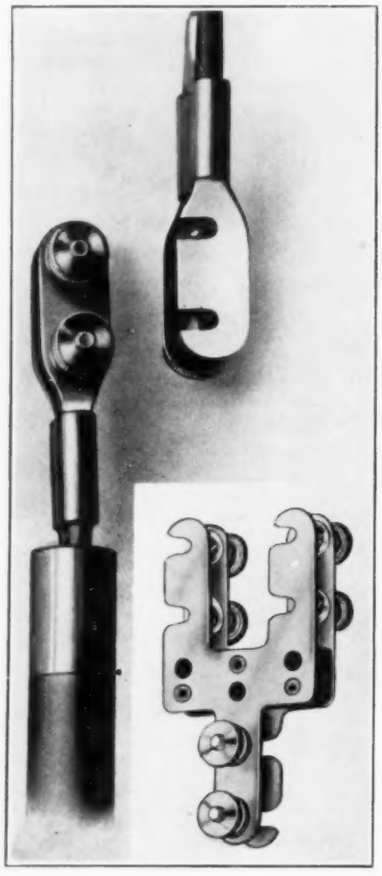


Fig. 55. Purposely shown here twice as large as in maker's catalog—to emphasize importance of good contacts in pyrometry.

Special connections for thermocouples. *(The Bristol Company).*

TABLE IV. PRINCIPAL CHARACTERISTICS OF THERMOELEMENTS

(Exclusive of temperature-emf relations, for which see Chart I)

Where two temperatures are given, higher is for thickest wires and lower is for thinnest wires commonly available. Degrees are FAHRENHEIT

Couple.....	Pt / Pt-Rh	Copper / Constantan	Iron / Constantan	Chromel / Alumel	Chromel X / Copel
Lowest temp. for satisfactory results (1)	32°	Approx. −400°	Approx. −400°	Approx. −400°	Approx. −400°
Highest temp. for good results; BARE couple in air	———	350° to 560°	600° to 1300°	1200° to 2000°	600° to 1000°
Highest temp. for good results, BARE couple in molten metals	———		600° to 1200°	1000° to 2000°	——— ———
Highest continuous temp. for good results, usual protection (2)	2400° to 3000°	350° to 650°	700° to 1560°	1200° to 2000°	700° to 1100°
Reproducibility (3)	Excellent	Depends on 'constantan'	Depends on Sources	Excellent	Good
Resistance to corrosion (normal use)	Perfect	Fair	Fair	Good	Good
Resistance to oxidation at highest temp.)	Perfect	Fair	Fair	Good	Good
Standard diameters of wires	B.S.gages 30 to 20	B.S.gages 36 to 2	B.S.gages 32 to 2	B.S.gages 30 to 2	B.S.gages 30 to 2
Approximate cost of best wires	$2.00 per inch of 24 gage couple	$1.50 per lb.	$2.50 per lb.	$2.50 per lb.	$2.50 per lb.
Especially useful for	Standards and precision work	Low temperature	———	Oxidizing atmospheres	
Not recommended for	Use with silica tubes	———	———	Reducing atmospheres	

(1) Thermocouple tip being measuring junction; and reference junction the hotter of the two.

(2) Temperature of the elements—not necessarily temperature to be controlled. See text.

(3) Reproducibility or interchangeability—Uniformity of electrical characteristics in order that successive purchases of wire will have same characteristics.

10. Thermocouples

There is a trend toward standardization of thermocouples, in that a few industrially successful thermo*elements* emerge as industry's favorites while others are relegated to unusual applications. But when it comes to the mechanical construction of *mountings* and *accessories*, variety grows greater with almost every new catalog. On the whole this is a healthy situation:

(a) Little choice of *elements*, so that users are not embarrassed when faced with making a decision;

(b) A pleasantly wide choice of *constructions* for all important applications;

(c) A growing number of "specials," each made to order for some industry or *standardized* piece of equipment. (These include complete indicating systems, quantity-built and assembled, consisting of thermocouple, cable and millivoltmeter indicator—all "ready to use").

Thermoelements

Every conceivable pair of materials has limitations as well as definite advantages. In the laboratory, one can select any two materials, buy or make thermoelements, work out a circuit, handle the cold junction and calibrate an instrument for use with that one particular couple and circuit; in the plant this procedure violates all canons of scientific management. Interchangeability is essential for production work, and the chances are against unusual elements being so reproducible that the instrument scale will not need recalibration for each individual couple. The elements on the market are standardized and almost perfectly interchangeable within each type (See Table IV). The commercial instruments come with indicating scales and printed recorder charts graduated in degrees of temperature and read or record correctly for particular types of thermoelements, which are believed to be the most suitable, all things considered.

The thermoelements on the market are as follows:

1. *Rare-metal*—Platinum to platinum-rhodium, the alloy being available in two compositions: (1) 90% Pt. and 10% Rh., (2) 87% Pt. and 13% Rh.

(Reason for two compositions: until the National Bureau of Standards settled the matter, it was believed that there were two "types" or "classes" of Le Châtelier (90-10) couples. One was found to contain impurities. It ceased to exist as a "type" or "class." To take care of the many instruments calibrated for it, the 87-13 was developed—whence more sales of couples, then of instruments, then of more couples, and so on.)

2. *Base-metal*—Ninety percent or more are iron-constantan, chromel-alumel, or copper-constantan. Other combinations are giving satisfactory service and there is no intention to recommend against their use.

(The terms "Constantan," "Cupron," "Copel," "Advance," "Ideal," "Copnic," etc., are trade names for copper-nickel alloys, the exact proportions of these two metals and of additional ingredients being such as to give the curve wanted by particular pyrometer manufacturers. "Alumel" is mostly nickel, "Chromel" too but with about 10% chromium.)

3. *Graphite to silicon carbide*. This couple, announced in 1933*, was developed particularly for the pyrometry of liquid iron and steels.

*G. R. Fitterer. A New Thermocouple for the Determination of Temperatures up to at least 1800°C. *A.I.M.E. Transactions*, Vol. 105, 1933, pages 290-301.
Also *A.I.M.E. Transactions*, Vol. 120, 1936, pages 189-216.
Also *Iron Age*, Vol. 140, July 22, 1937, pages 38-40.

Chart I. Temperature-emf. relations

(Reference junction at 0°C. in each case)

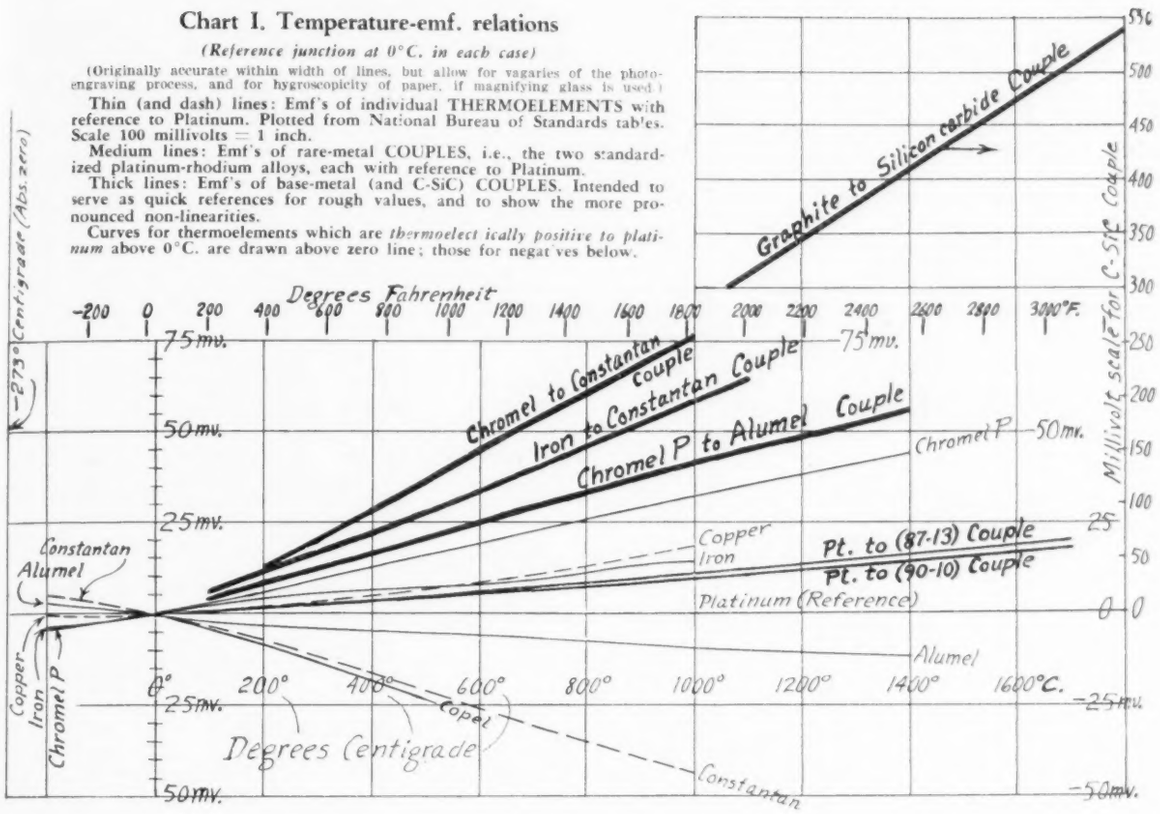
(Originally accurate within width of lines, but allow for vagaries of the photo-engraving process, and for hygroscopicity of paper, if magnifying glass is used.)

Thin (and dash) lines: Emf's of individual THERMOELEMENTS with reference to Platinum. Plotted from National Bureau of Standards tables. Scale 100 millivolts = 1 inch.

Medium lines: Emf's of rare-metal COUPLES, i.e., the two standardized platinum-rhodium alloys, each with reference to Platinum.

Thick lines: Emf's of base-metal (and C-SiC) COUPLES. Intended to serve as quick references for rough values, and to show the more pronounced non-linearities.

Curves for thermoelements which are *thermoelectically positive to platinum* above 0°C. are drawn above zero line; those for negatives below.



The characteristics of interest fall into two classes:

(1) The temperature-emf. relation. This is given in Chart I.

(2) Service characteristics. The principal ones of these are given in Table IV. Others follow:

General Notes. (1) The thermal emf. of an individual couple at any temperature difference between its two junctions depends to some extent upon the history of each thermoelement: the original refining, melting and alloying processes, the hot- and cold-working operations employed by its manufacturer, the final heat-treating processes, etc. Hence the common proviso, "from lot to lot," in references to reproducibility of the temperature-emf. curve. Up to the early nineteen-twenties, it was almost hopeless to expect reproducibility "from source to source." The situation has been improved so much by the National Bureau of Standards that different sources agree better today than different lots from one source did shortly after the First World War.

(2) The term "accuracy" generally refers to agreement with a given curve, which may be the manufacturer's own curve for the particular couple. This applies only to base-metal couples today, but note that *all old literature* (textbooks and manufacturers' publications) gives statements and curves no longer true today. Unfortunately, there is no definite date separating "old" and "new" literature, because standardization has been gradual and is still going on. In doubtful cases, look up the latest National Bureau of Standards' publication on the uncertain point.

(3) A couple suitable for use in oxidizing or reducing atmospheres at "safe" temperatures should be used in either, but not in one after having been used in the other —whatever the temperatures of the first and second.

(4) Much of the manufacture of thermoelements being still an art, with guarded secrets, it is not unusual for one particular source to guarantee one particular type of couple within marvelously close limits, and for the users to find year after year the guaranteed closeness to the curve.

Rare-metal. While their first cost is several times that of base-metal couples (made of wires of same gages and lengths) these couples are seldom more expensive in the long run. The reasons are practical rather than theoretical: In the first place, their outstanding reproducibility and stability permits their being selected for applications where extreme accuracy is required and where—consequently—precautions are not overlooked. In the second place, their chief weakness (silicon contamination) is so well-known that precautions are redoubled. Thus it frequently is reported that the cost per furnace per year of using rare-metal couples is smaller than for furnaces where base-metal couples are used.

The chief limitation of rare-metal couples (not mentioned in Table IV) is that they require *special* protection, particularly in reducing atmospheres. Silicous materials must be avoided.

Rare-metal couples are frequently used bare in the laboratory—but both thermoelements are so easily contaminated that extreme precautions must be taken. When contaminated, they can in many cases be restored to good condition. National Bureau of Standards publications give directions for removing some surface impurities, restoring homogeneity of microstructure, etc.

Maximum deviation from the two standard curves (recognized by all manufacturers) is seldom more than 5°F. at 2000°F. for new couples. Such an "error" is not even observable on the scale of an ordinary millivoltmeter pyrometer. As a rule, a new rare-metal couple can confidently be used in the plant without having been checked by the plant instrument department.

A rare-metal couple and a high-grade portable potentiometer constitute the equivalent of an inspector's gage which is taken around to check ordinary pressure gages BUT note that the temperature reading given by any couple is the temperature of its measuring junction, so that with different protections and different immersions, two perfect couples may give widely different readings of the same furnace temperature.

Iron-Constantan. When Table IV was first published, objections were made to the brevity of the recommendations under "Iron-constantan." The author consequently request-

ed Dr. I. M. Stein* to prepare a definite statement, which follows:

". . . A correct statement of the situation cannot be made quite so briefly, but we shall attempt to give you our ideas as briefly as possible.

"1. The iron-constantan couple used under proper conditions gives a more reliable relation between emf. and temperature than any other type of base metal couple.

"2. In an oxidizing atmosphere, particularly at temperature above 1400°F., the life of an iron-constantan couple is much reduced so that for such services the chromel-alumel couple is usually recommended in spite of its less reliable temperature-emf. relation.

"3. In some reducing atmospheres, the iron-constantan couple theoretically would be subject to errors due principally to the action on the constantan. However, the reducing atmospheres that are usually encountered in practice are of such nature that the iron-constantan couple is not appreciably affected and is the one usually recommended for reducing atmospheres."

In 1940, the Leeds & Northrup Co. published a thermocouple catalog in which still another point was brought out, namely, the enormous difference between the temperature limits recommended for the smallest and heaviest wires. This has been incorporated in Table IV. This difference is greater than for any other pair of industrial thermoelements.

Copper-Constantan. This couple is not recommended for temperatures above 600°F., because the copper would oxidize too rapidly, although it is suitable for both reducing and oxidizing atmospheres. Interchangeability between different couples and from lot to lot can be guaranteed within smaller limits than other base-metal couples; about 6°F. Frequently this type is used with multiple junctions, i. e., several couples in series, for work in small areas where quick readings are desired. (Example: thermopiles for radiation receivers of high precision.) At the low temperatures for which this couple is suitable, no primary or secondary protection other than insulation, is ordinarily required. When used in acid fumes or under other corrosive conditions, a thin-wall transparent quartz-glass or hard porcelain tube is adequate protection.

Chromel-Alumel. Best service will be obtained when used in oxidizing atmospheres. Interchangeability from element to element and lot to lot, is generally guaranteed within 15°F. The somewhat lower degree of interchangeability of these as compared with iron-constantan is in part offset by the fact that they can be used for a higher temperature range. Some manufacturers have recommended this type for temperatures as high as 2300°F. This is possible for short periods of time only, even with the heaviest wires.

Conditions of Use of Couples

Before passing on to protection tubes and mountings, a few miscellaneous notes on conditions of use in general:

Cold-working alters the curve of most elements. Swaging, bending and twisting the wires near the weld does not matter so much as sharply bending a portion which will be exposed to a temperature gradient. The steepest gradient, of course, is at a furnace wall. Therefore, even double-protected couples must be handled with this in mind.

Remember that for an equal exertion of finger-muscle strength, the area stresses in a small-gage wire are much greater than in a heavy wire; also that the seriousness of "surface" impurities is in inverse ratio to diameter.

All connections (Fig. 55 type or other forms), switches, conduits, fixtures, etc., should be enormously heavier than theoretically required by the feeble "wattages" involved. It is precisely because the emf's are millivolts that clean contacts and large surfaces of high-grade power-rating switches are essential to prevent variable-resistance errors and other sources of erratic readings.

The reference junction, as has been seen, is usually two junctions (*A* to brass, brass to *B*). The same condition may apply to the hot junction. Its wires need not touch if they are immersed in molten metal, or rubbed and pressed hard against a metal surface. There are many uses for a bare couple. For temperature of solid metal parts (bearings, etc.) the wires may be peened into the metal. In all such cases the two wires should be *close together* because a difference of temperature at their respective entrance points will set up an additional emf.* In all such cases, too, it should be noted that the surface temperature is the one which will be indicated. Welded or twisted couples dipping in slightly conducting liquids should not be immersed deeply.

Radiation and conduction always affect the readings of couples. The couple will develop the emf. due to its own temperature, but its own temperature may be different from that of the medium. Remember that the wires conduct not only electricity but heat. Where a high order of accuracy is desired in measuring "furnace temperature" in the sense of furnace atmosphere temperature, the couple tip should be surrounded by a sleeve to prevent its "seeing" surfaces colder or hotter than the atmosphere and giving or receiving radiation to or from such surfaces. (The A.G.A. recommendation is given under "Forms of Assembled Thermocouples.")

Arranging a number of hot and cold junctions in series ("thermopile") will give the sum of the emf's; in parallel, the average; but resistance addition or division, non-linearity, and other conditions, modify the exactness of the theoretical values. Industrial users may well leave the design and construction of thermopiles, etc., to specialists.

Forms of Assembled Thermocouples

The few illustrations on these pages convey but a slight idea of the variety of thermocouple assemblies, tubes, fittings, etc. The judicious choice of these adjuncts often has a more important bearing on the success of an installation than has the choice of a particular make of instrument.

Fig. 56 is a composite of illustrations from a publication issued only a week before this writing. The caption follows the manufacturer's data. In addition, the good drawing of the improved head affords an opportunity to bring out a point seldom mentioned in texts, though important. Note that this design makes for temperature equality of the two

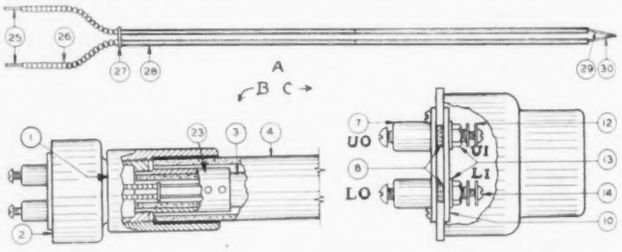


Fig. 56. Rare-metal wires 29 and 30, welded at the right-hand end, constitute the pair (not "thermocouple") 25. This is the primary measuring element of a thermoelectric pyrometer. Therefore, 25 is known as an element. This element is insulated by the two single-hole insulators 28 and by fish-spine insulators 26. The resulting assembly A is enclosed in porcelain primary-protecting tube 3. This, in turn, is enclosed in porcelain secondary-protecting tube 4 with ferrule 1, sleeve 23 and head 2 completing the entire assembly B. Details of a head slightly different from 2 (no outside pipe-thread) are shown at C. *(Leeds & Northrup Co.)*
See text for significance of other letter symbols added by the author.

outside connections *O-O*, and temperature equality of the two inside connections *I-I*. Thus, because of the rule of symmetry, it is not necessary to maintain the *inside-and-outside* ends *U-U* of the upper connecting stud at the same temperature, nor to maintain *L-L* at the same temperature, provided of course that the various metals of the upper and of the lower connection devices are identical in composition, etc. Now imagine the consequence of a worker "tagging" this couple (as is sometimes done in the best plants) by placing a sheet of cardboard *between* the outer terminals. This cardboard will shield only one of the terminals from nearby sources of radiant heat and the reading will be seriously affected. Therefore, when installing ther-

*Director of Development, Leeds & Northrup Co.

*Dr. Roeser has recently given (ref. cited) several figures showing the seriousness of this effect. His final illustration is that of a rare-metal couple with its two wires attached to two points whose temperatures are 700°C. and 750°C.: under the conditions he describes the "reading" is 962°C., or 267°C. higher than the 725°C. average.

couples, do not consider the job complete until you have provided against what "the other fellow" might do.

Reference was made above to "specials" which are really standard for some industrial process. Among these are the following:

"Mold" thermocouples with a small contact area, especially useful for work with plastics.

For brass, bronze and aluminum foundries, thermocouples are made with unwelded elements at the end of convenient handles, which hold two spools—one for each wire. The life of the immersed ends is short but they are trimmed easily. There is also a heavy-wire non-reeling type, the advantage of which is longer life.

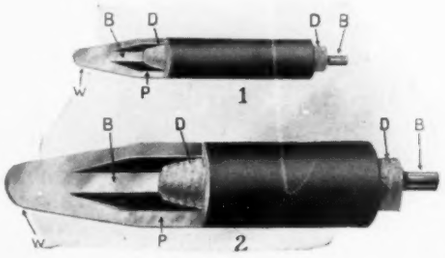


Fig. 57. Actual size part-section views of couples consisting each of an iron tube P welded at W to a constantan wire B which is insulated by asbestos cord D. Larger size can be used bare up to 1250°F., smaller up to 800°F. *(Foxboro Co.)*

For high temperature work where reliability of indication is of greater importance than accurate measurement of temperature, and where it is desired to protect rare-metal thermocouples as much as possible, the final protection may take the form of silica blocks designed to be built into the crown of the furnace. (Fig. 59).

Surface-contact thermocouples are made in numerous forms, including even one made by Taylor especially for hotel ranges. The great majority are "specials"—not only because they are designed for convenient use but particularly because the measurement of *true* surface temperature is practically impossible. There is no universally satisfactory combination of couple and mounting. This subject is discussed in the Bureau of Standards' Research Paper No. 231 by Roeser and Mueller, also in Sosman's book "The Pyrometry of Solids and Surfaces."

Perhaps the most interesting assemblies are the "aspiration pyrometers" for measuring "true" gas and flame temperatures by eliminating or minimizing errors due to radiation, conduction and convection. Fig. 58 is the form recommended by the American Gas Association and the following is an abbreviated extract from a report* by E. O. Mattocks, A.G.A. Industrial Engineer:

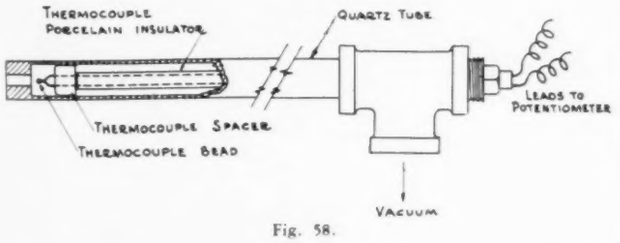


Fig. 58.

The "American Gas Association High-velocity Thermocouple" consists of a translucent quartz tube which is partly closed at one end, while the other end is connected to a vacuum line. Inside this quartz tube the thermocouple is so placed that the bead is located a short distance behind the small opening in the restricted end of the quartz tube, and centered by a porcelain spacer.

The assembly is inserted into the hot gas stream, locating the perforated end at the place where the temperature is desired. A period of time is then allowed to permit the quartz tube and thermocouple to come to equilibrium temperature. (For reasons to be shown later, this reading is generally recorded.) The vacuum is

*E. O. Mattocks. A Precision Couple for Measuring Gas Temperature. *Metal Progress*, July 1934, pages 37-40.
E. O. Mattocks. Temperature and Its Measurement. *Industrial Gas*, August 1934, pages 15-18, 22.

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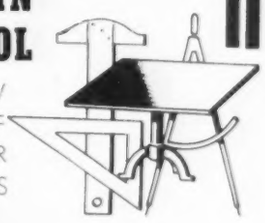

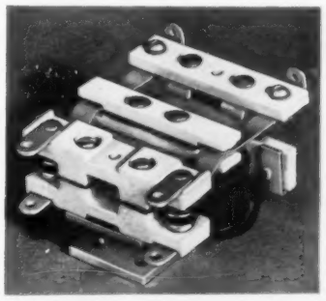

This Kurman relay was designed to meet the need for a high quality medium duty relay at low cost. The magnet coil is wound on a Bakelite core and Alsimag non-hygroscopic insulation is employed. Contacts are quarter inch coin silver.

KURMAN ELECTRIC CO.
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241 Lafayette Street, New York, N. Y.

WL

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for Every Job

The Ward Leonard Pressed Steel Plate Type Rheostat is a most adaptable control device. It lends itself to front or back of board mounting, multiple assembly, concentric operation and manual or motor drive. Thus whatever the control requirements or method of operation may be, Ward Leonard, with their wide range of rheostat mountings and accessories can give you on short notice the exact combination to do the job. Ward Leonard Plate Type Rheostats are described in Bulletin 60. Ring Type Rheostats in Bulletin 1105. Laboratory Rheostats in Bulletin 8002. Send for Bulletins of interest to you.

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then turned on and a short time permitted to elapse before the temperature is again read.

The following conditions must be satisfied to obtain the true temperature of the gas:

1. The time interval between applying the vacuum and taking the temperature reading must be long enough to permit the thermocouple bead to become thoroughly heated to the temperature of the flowing gas.

2. The vacuum must be sufficient to create a relatively high gas velocity past the thermocouple bead, for there should be no temperature drop between the gas entering the quartz tube and that passing the thermocouple bead.

3. The velocity past the thermocouple bead must be high enough to supply heat to the bead faster than the bead can radiate heat to the tube surrounding it.

4. The tube surrounding the thermocouple bead should possess low absorption and high reflection factors.

It is advisable to draw a check curve plotted from readings taken both before and after the vacuum is applied, for several different equilibrium temperatures. These readings must be taken with the assembly in the same location. By plotting the indicated ("no vacuum") temperature against the true ("vacuum") temperature, a straight line should result. If any pair of observations do not plot on this curve, it is advisable to check the readings with a new bead or an entirely new thermocouple.

Protecting Tubes

For high-temperature work the protecting tubes are of far greater *practical* importance than the thermoelements.

The following properties (as listed by the Bureau of Standards) should be considered in reference to the particular process for which the tube is required:

(1) Low porosity to gases. Many tubes become porous to furnace gases at high temperatures.

(2) Low volatility. Certain metal tubes are undesirable at high temperatures because the metal distills upon the couple, thus altering its calibration.

(3) Ability to withstand high temperature.

(4) Ability to withstand sudden changes in temperature.

(5) Ability to withstand mechanical shocks and strains.

(6) High rigidity. Protecting tubes frequently deform and exhibit the phenomenon of plastic flow at high temperatures.

(7) Thermal conductivity. High thermal conductivity is frequently desirable when rapidly changing temperatures are measured. Usually, however, low thermal conductivity is desired so that the flow of heat along the tube be as small as possible.

(8) Ability to resist corrosion from molten metals or furnace gases.

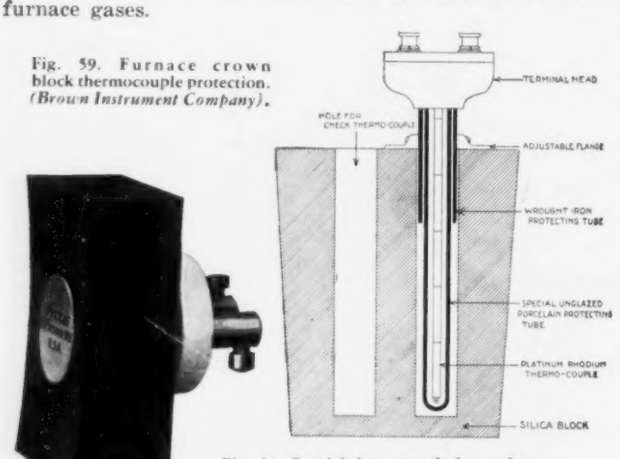

Fig. 59. Furnace crown block thermocouple protection. *(Brown Instrument Company).*

Fig. 60. Special shape couple for surface temperature of mill rolls, glass cylinders, etc. To save wear, this unit is often fastened to a rod in such a way that it may be pressed against the roll only when it is desired to read the indicator. *(Taylor Instrument Companies).*

12. Some Troubles—Causes and Remedies

Among common causes of slight or serious errors in the use of thermoelectric pyrometers there may be noted the following:

First and foremost—*Poor Connections*—loose, corroded, oily, dirty, etc., etc.

Next—Short-circuits inside thermocouple stem caused by worn or broken insulators. Then:

Locating instruments too near sources of heat. Even with automatic compensation of cold junction in instrument case, this is poor practice. Such compensation may not be designed to take care of serious increase in coil resistance (and hence lower torque) due to excessive temperature. No compensation is designed to nullify the effects of gradients in the instrument case.

Locating instruments where they are subjected to excessive vibration and shocks. Even one sudden jar may cause two or more turns of a spiral spring to catch one another. Same effect as shortening spring, which opposes coil: Readings will be too high.

Inadequate protection from dust, fumes and moisture.

Altering length of extension and even of copper leads.

"Repairing" broken or worn extension leads with unsuitable wires. May cause an error of 15% of range.

Even in replacing compensating leads with properly chosen new leads, reversing polarity will cause errors.

Various unforeseen causes of change of lead resistance.

Running leads close to furnaces, etc., for long distances: commercial wiring is not perfectly homogeneous—and even if it is, the variable resistance will cause errors unless a true potentiometer is used.

Neglecting to check with open circuit.

Neglecting to verify temperature of buried cold junction by lowering a thermometer tied to a string, which should be done once a month.

Neglecting to inspect thermostated junction or zone boxes.

Neglecting to test contacts of multiple and other switches.

Variable immersion of long thermocouples.

Allowing ashes, dust, clinkers or other material to accumulate on the end of the protection tube.

Using instruments scaled for one pair of thermoelements to measure temperature by the emf. produced by a different couple.

Impairment of homogeneity of thermocouple wires where exposed to temperature gradients. Such impairment is usually caused by contamination (cracked protection tube, etc.).

Induced currents, stray leakage, etc. Wherever there are electric furnaces, electrical machinery or even the usual plant wiring, in the close vicinity, the original installation should be made by a trained man. This is especially true of multiple-switching circuits.

Voltaic effects arising from worn insulation plus moist wood, etc., between leads of dissimilar materials.

The "Becquerel effect," set up sometimes when tubes are not gas-tight and themselves emit a gas which contaminates the couple. For example, silicon on platinum: an additional thermocouple is created. Sometimes remediable by annealing the wire.

If the pointer wobbles, there is trouble somewhere—probably a loose connection or defective insulation. Located by shaking one part of the circuit after another.

Checking procedure and table of fixed points will be found in the Appendix.

In conclusion, *apply the Rule of Symmetry.*

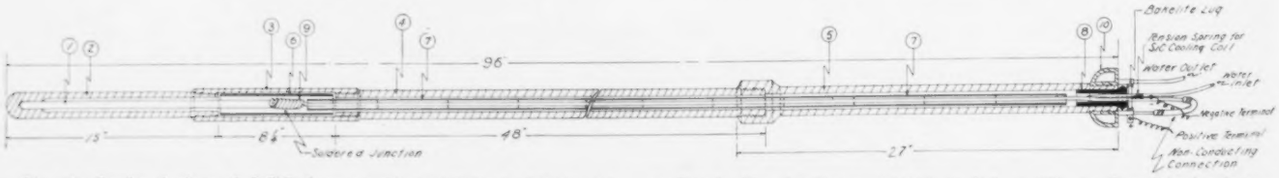

Fig. 61. Sectional view of C-SiC thermocouple assembly. 1—Silicon carbide rod. 2—Graphite tip. 3—Graphite sleeve. 4—Graphite main section. 5—Graphite head nipple. 6—Fused silica insulator ($1\frac{3}{8}$" × $1\frac{1}{8}$" × 8"). 7—Fused silica insulators (25/32" × $\frac{5}{8}$" × 5"). 8—Porcelain insulator. 9—Copper cooling coil for SiC. 10—Copper cooling coil for graphite. *(Fitterer Pyrometer Co.)*